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Preface

Japan is one of a few countries where people have paid attention to the decrease of seaweeds for more than a century. In the east coast of Izu Peninsula, Central Pacific Coast of Japan, fishermen called the decrease of *Gelidium* or *Ecklonia* 'isoyake' . Since the first literature in 1885, the dialect has been applied to refer the decrease of a variety of 'moba' (useful seaweed beds) including *Saccharina* in northern Japan, *Eisenia* and *Sargassum* in central to southern Japan. The causative agents of isoyake vary from natural to anthropogenic. In a hundred and twenty years since 1885, more than 1,000 papers have reported the occurrence and ecology of isoyake and trials of seaweed bed restoration. However, deforested areas have continued to increase even in the 21st century and successful restorations of seaweed beds have been quite limited. In Japan extending long from south to north, we can see various types of isoyake. The recent characteristic phenomena are 1) increase of urchin barrens by *Anthocidaris* or *Diadema* in southern Japan, 2) long persistence of urchin barrens by *Strongylocentrotus* in northern Japan, 3) deforestation by herbivorous fish (*Siganus, Calotomus, Prionurus* and *Kyphosus*) in southern Japan, and 4) occurrence of barrens by stagnation of waters and/or sedimentation near highly protected areas. The stagnation of waters may not only weaken seaweed thalli, but enhance the destructive grazing and browsing by herbivores. Elevation of water temperature relating to global warming (?) is one of the greatest concerns as a causative agent or background of isoyake, but the trend of fluctuation differs spatially and temporally. On the other hand, a variety of human activities (changes of coastlines and rivers, fishery, aquaculture etc.) may directly or indirectly affect the seaweed beds. For a long time, fishing villages and local governments have tried to increase seaweed beds by traditional hard techniques such as deployment of stones and concrete blocks. However, these techniques are not the measures to restore seaweed beds on deforested bottoms, particularly when the densities of the herbivores are high and not controlled. The invested hard substrata seldom restore seaweed beds but even worsen the conditions because of providing habitats for herbivores.

In Japan, 'Isoyake Taisaku Guideline' was published in 2007 by Fisheries Agency and the following projects are ongoing to popularize the principle as well as to practice the restoration of seaweed beds all over the country. The communities of seaweeds and the related fish and shellfish are local, but most of the component species are Indo-Pacific, common in East Asian countries. Recent exploitation and export (to Japan) of these marine products may also have impacts on the coastal resources and their management in both of exporting and importing countries. Also for global warming, we should exchange information to broaden our view from the different sides of the common sea. The present symposium was held at Zenko Suzuki (the 70th Prime Minister, 1911-2004) Hall in Tokyo University of Marine Science and Technology on August 1st 2008 to learn current status of seaweed beds, isoyake and their restoration not only from Japan but from other regions of East Asia and in a global scale to deepen our knowledge, to understand each other and to find out the better way of managing healthy seaweed beds and the related coastal resources. We believe this symposium is the first synthesis of wisdom in East Asian countries and provide the base for further collaboration on this theme.

We would like to thank to Fisheries Research Agency, Fisheries Agency and Tokyo University of Marine Science and Technology for cosponsoring this symposium. Second, thanks go to Dr. Dmitry Galanin from Russia and Dr. Rae-Seon Kang from Korea, Drs. Jianting YAO, Delin DUAN and Putt O. Ang, Jr. from China, and Drs. Jui-Sheng Chang and Chien-

Chang Tseng from Taiwan and Dr. Michael Graham from United States, who joined the symposium and gave us useful information. We also thank to staffs in National Research Institute of Fisheries Engineering and students in Laboratory of Applied Phycology, Tokyo University of Marine Science and Technology for technical assistance during the symposium and staffs in Shizuoka Prefecture for aiding the excursion and a satellite symposium at Numazu City Office.

Organizers
Daisuke Fujita
Hisami Kuwahara

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Balance between harvesting pressure and protection: Implications for barren ground formation in Hong Kong

P.O. Ang, Jr.[*1], K.Y. So[*1], T.W. Li[*1], F.F. Yeung.[*1], S.Y. Wong.[*1] and C.K. Woo[*1]

Abstract: In recent years, there is an increasing awareness of the importance of coastal communities as ecological habitats. Marine protected areas (MPA) are being established and harvesting of marine organisms within these protected areas is being regulated. MPAs provide an opportunity for dynamic regulating mechanisms within coastal community to be examined. A case in point is the Tung Ping Chau Marine Park (TPCMP) in Hong Kong established in 2001. From October 2002 to March 2004, temporal variations in algal and herbivore dynamics were observed in general monthly surveys. The density of herbivores in Lung Lok Shui (LLS), one of the sites known to support extensive bed of *Sargassum*, was low (0.76 individual/100cm^2) and herbivores did not appear to be an important factor in structuring the algal community.

In 2006 to 2007, the population of the short-spined black urchin *Anthocidaris crassispina* increased significantly, from < 1 individuals/m^2 in pre-MPA period to up to 40 individuals/m^2, likely a result of restricted harvesting of these urchins since the establishment of TPC as a marine park. One serious and unexpected consequence of this was the decimation of *Sargassum* population in LLS due to extensive urchin grazing. The cover of *Sargassum* was completely reduced, forming barren ground. Sea urchin grazing became the most important structuring force in this coastal community and was previously put under check due to harvesting by human. A question can therefore be put forward as to how important is human harvesting pressure on sea urchins, or other herbivores like fish, contributing to the dynamics of the coastal algal community. This factor may be more important than previously thought.

Introduction

Hong Kong is located in the southern part of mainland China to the east of the Pearl River, the third largest river in China. True marine environment is therefore found only along its eastern coastline whereas the western coast is highly influenced by the Pearl River outflow and hence is brackish. Rocky shores supporting marine algae are not extensive and these do not usually extend to great depth beyond 10m below the chart datum (CD). Largely because of the influence of the Pearl River, sea water around Hong Kong is highly turbid. Hong Kong has a subtropical monsoonal climate with mean sea water temperature ranging from 14℃ in winter to 28℃ in summer. More than 299 species of macroalgae (seaweeds) have been recorded within Hong Kong waters (Ang 2005). These include temperate as well as tropical species. Their abundance is highly seasonal. Many of these appear as turf that forms a thin carpet on the rocky surface especially during summer. Larger algal species appear mostly in late fall to spring. Perennial to pseudo-perennial species like *Sargassum* spp. provide the canopy to support large number of zooplankton and epiphytic flora and fauna (Ng 2009).

Changes in physical and chemical parameters in the environment, including tide, temperature

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and light are some of the forces structuring algal communities. Biological interactions, including competition and herbivory, are also important (So 2005). The level of intensity, periodicity and regularity of these interactions at the temporal and spatial scales can affect the abundances and diversities of algal populations at a particular locality. Ultimately, the characteristics of individual species or populations, including their physical form, reproductive behavior, fecundity and functional physiology could also determine their tolerance to changes in the environmental conditions.

Herbivory as a structuring force in Hong Kong algal communities is understudied. Large scale grazing by sea urchins, resulting in barren ground (isoyake) formation in many places around the world is well documented (e.g. Watanabe and Harrold 1981, Vasquez *et al.*, 1984, Himmelman & Nedelec 1990). However, this phenomenon is largely unknown in Hong Kong until recently. This study explores aspects of herbivory as a structuring force in Hong Kong algal community, with particular focus on

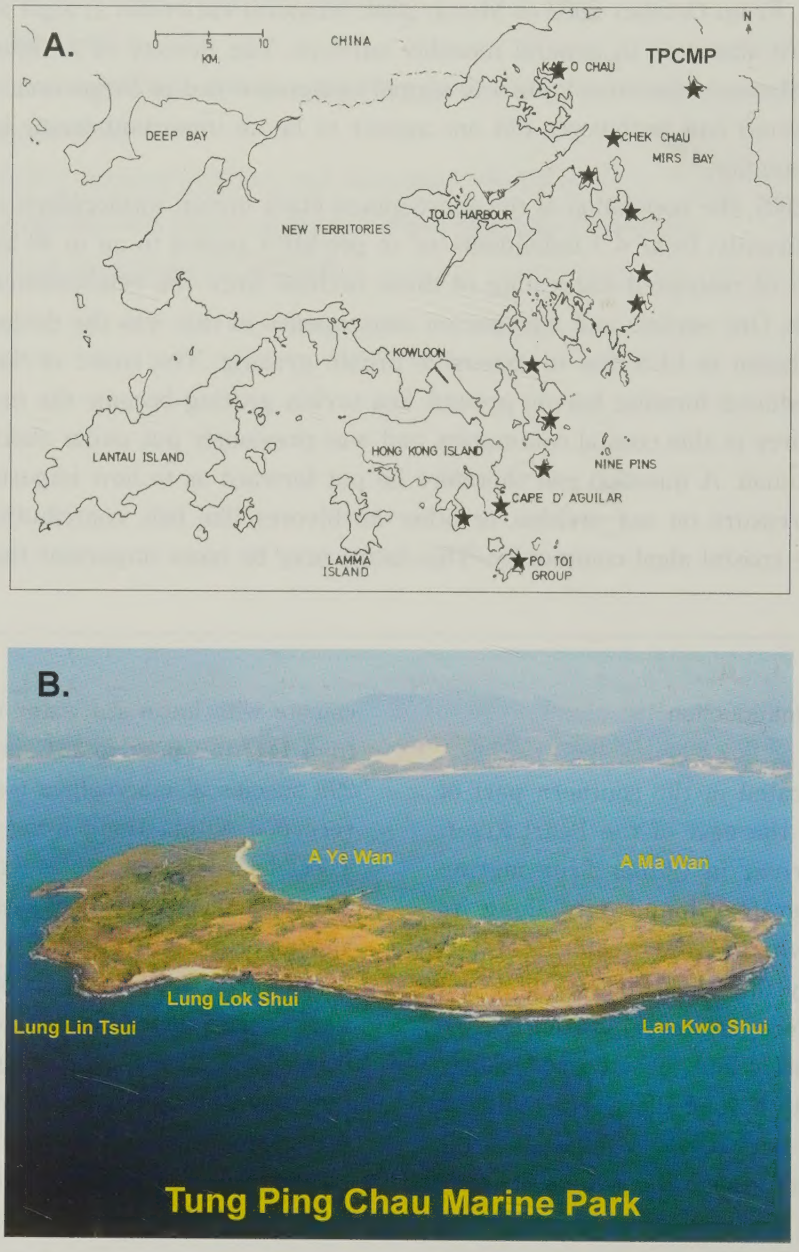

Fig. 1. Map of Hong Kong showing **A.** the location of Tung Ping Chau Marine Park (TPCMP) and other sites (marked with ★) with known abundance of *Sargassum* spp.; **B.** detailed picture of TPCMP with location of the sites mentioned in this study. (Photo Courtesy: AFCD of Hong Kong SAR Government)

sea urchin grazing in a marine protected area, the Tung Ping Chau Marine Park (TPCMP). Sea urchins, especially the short-spined black urchin *Anthocidaris crassispina*, are harvested resource in Hong Kong. They are prized for their gonads locally or are harvested for export. The earlier study on the density of *A. crassipina* in Tung Ping Chau before it was designated as a marine park in 2001 enables a comparison to be made on the density and size of this sea urchin before and after marine park designation. Furthermore, continuous monitoring of the phenology of *Sargassum siliquastrum* in the same site made possible a correlation to be made between the density of the urchins and that of the seaweed. The increase in the number of *A. crassipina*, most plausibly due to its protection after Tung Ping Chau was designated as a marine park, has brought some unexpected impact on the seaweed flora in the protected area.

Study Site

Tung Ping Chau Marine Park (TPCMP) is located on the northeastern corner of Hong Kong territorial water (Fig. 1). Because of its relative remoteness to the highly urbanized Hong Kong, it still enjoys a relative protection from many human disturbances that are characteristics of many other coastal areas in Hong Kong. A Ye Wan (AYW) and A Man Wan (AMW), on the north to northeastern side of the island (Fig. 1), support a high cover (>50%) of hard corals. But high diversity of algae can also be found in their shallower rocky shores especially in winter. Lung Lok Shui (LLS), on the other hand, is located on the south to southwestern side of the island. It is exposed to strong waves especially in summer. It supported extensive beds of *Sargassum*, mainly *S. hemiphyllum* in the lower intertidal and *S. henslowianum* and *S. siliquastrum* in the subtidal. Population of *S. siliquastrum* extended all the way to 10m depth below CD, forming one of the largest seaweed beds in Hong Kong. The presence of this extensive seaweed bed, together with high covers of corals in AYW and AMW, were the reasons behind the designation of Tung Ping Chau as a marine park in November 2001. Changes in algal and herbivore densities in LLS are the focus of this study.

Materials and Methods

Measurement of Algal Percentage Cover

Algal percentage cover in LLS was examined monthly from December 2002 to March 2004. Seven 5m transects were laid parallel to the shore haphazardly. Four quadrats were placed on each transect which was marked with random points. The random point quadrat was 25cm x 25cm in dimensions, with 100 random points represented by intersections of cross strings. Algae underneath every random point were identified to the species level as much as possible. The percentage cover of each algal species was recorded by counting the number of random points that it covered. At times when there was more than one layer of algae under one point, the algae in the upper layer were recorded first, and were then pushed to one side to expose and count the algae in the lower layer.

Some algae were difficult to identify *in situ*. Filamentous algae less than 1cm in length were grouped as turf algae. Encrusting algae were also identified as a group. No attempt was made to examine the detailed species composition of the turf or encrusting algae.

Measurement of Herbivore Density

The position and number of quadrats were the same as those used in the measurement of algal percentage cover described above. The number of individuals of each herbivore species within the 25cm x 25cm quadrat was counted and identified to the lowest taxonomic level as much as possible. The sampling method for fishes was different. The observer would stay at 2m away from the plot and would count the number of fishes hitting the plot for two minutes. After recording, the number of individuals for each herbivorous species per quadrat, including fishes, was standardized and expressed as number of individuals/100 cm^2 in the analyses.

Density and size of *Anthocidaris crassispina*

Other than the density of herbivores measured above, the density of the sea urchin *Anthocidaris crassispina* and its sizes in LLS were separately measured *in situ* on a monthly basis in 2000, then in 2006-07 and 2008-09. Eight transect lines, each

20m long, were laid out haphazardly, in a direction perpendicular to the shoreline. A cave in LLS was used as a reference point to allow rough estimation of the position of the study site. All transect lines were set at the shallow water region with depth between -3 to -5 m CD. A 0.25 m^2 quadrat was placed at 2m interval on the left side along each transect and all individuals of *A. crassispina* found inside the quadrat were counted. At the same time, the test diameter of each of these individuals of *A. crassispina* was measured with a vernier caliper to the nearest millimeter.

Phenology of *Sargassum siliquastrum*

Monthly monitoring for the growth and reproduction of *Sargassum siliquastrum* in LLS has been on going since 1996. In each month, 100 individuals of *S. siliquastrum* were haphazardly selected and its maximum length from the base of the holdfast to the tip of the longest lateral was measured to the nearest millimeter using a meter stick. The number of individuals that became reproductive was also counted.

Statistical Analysis

Relationships between the abundance of algae and herbivores were tested by Pair-wise Pearson Correlation. The percentage cover of algae and the density of herbivores, including herbivorous fishes, were correlated. Furthermore, Canonical Correlation was used to relate the abundance of the algal species and the density of herbivorous species in the whole community. Variables used in the analysis were defined as the variables measured in the study, such as the percentage cover of *Lobophora variegata*. Canonical variates were the linear combinations of these variables (Tabachnick & Fidell 1989). Two linear combinations of variables were employed in this study, representing the algal species and the herbivorous species. Each species was tested as one variable, unless the parametric assumptions of the analysis had been violated. In the latter case, the algal species *Amphiroa ephedraea, Caulerpa racemosa, Ceramium* spp., *Ceratodictyon spongiosum, Colpomenia sinuosa, Dictyosphaeria cavernosa, Dictyota dichotoma, Gracilaria verrucosa, Hydroclathrus clathratus, Hypnea japonica, Laurencia japonica*, and *Ulva lactuca* were grouped as others.

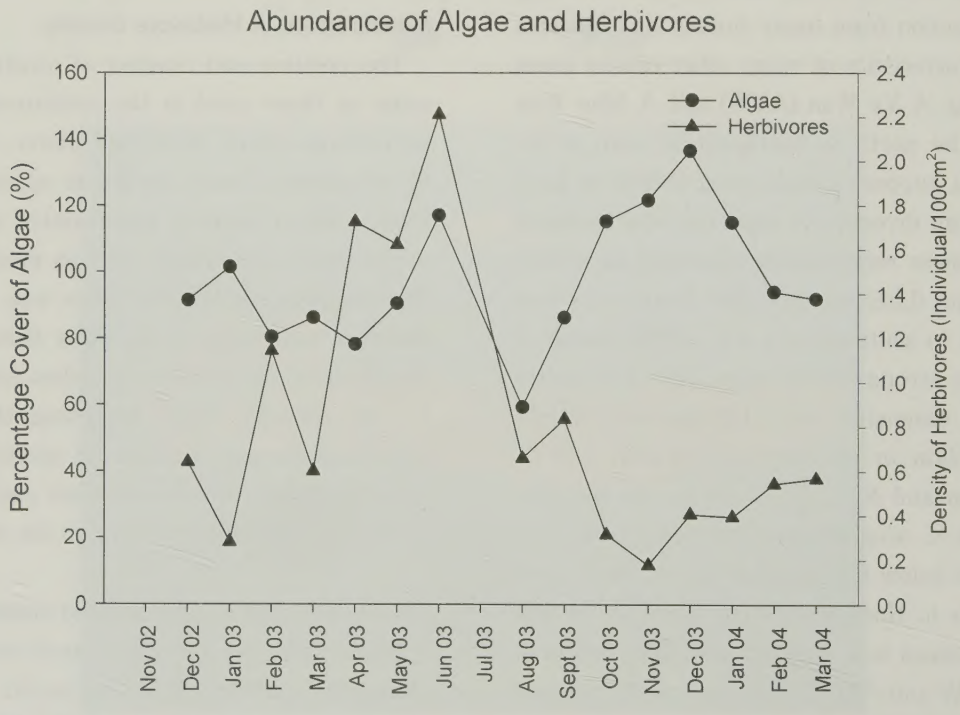

Fig. 2. Mean percentage cover (%) of algae and mean density of herbivores (Individuals/100cm^2) recorded in the general surveys from November 2002 to March 2004 in Lung Lok Shui. SD not shown.

Herbivores like *Epitonium perplexa*, *Signus japonica*, *Menaethius monoceros*, *Nerita albicilla*, *Flabellina ornate* and other small crabs were grouped as small herbivores. The significance of each canonical correlation was noted. For significant correlations, their canonical loadings with values that were <0.3 were not interpreted as they explained <10% of the variance (Tabachnick & Fidell 1989).

Results

Seasonal Variation in Algal Diversity and Cover

A total of 23 algal species were recorded in LLS. The species richness of algae was highest around February to April 2003 and the maximum number of species found in any single month was 16. Diversity of the algae remained high throughout the survey period with a peak shown in March 2003. *Sargassum* spp. were always the most dominant species recorded.

The yearly mean percentage cover (± SD) of algae was 93.6 ± 26.5%, ranging from 59% in August 2003 to 136% in December 2003 (Fig. 2). The peaks of algal coverage were in June 2003 and December 2003. Although there was a significant drop in algal cover in August 2003, the cover rebounded quickly. The results of Kruskal-Wallis one-way ANOVA indicate that the algal percentage cover was significantly different ($p < 0.05$, df = 14) among months.

Seasonal Variation in Herbivore Abundance and Diversity

Seasonal variations of herbivore density were observed in LLS. The densities of all herbivores, including fishes, increased in March 2003 and leveled off in May 2003. The density of the herbivores ranged from 0.18 – 1.14 individual/100cm^2 (Fig. 2) with a mean of 0.76 individual/100cm^2. Eighteen species of herbivores were recorded, with the highest diversity recorded in February 2003 and March 2004. The gastropod *Chlorostoma rustica* was the dominant herbivore within the period surveyed with the highest density of 0.95 to 1.17 individual/100cm^2 recorded in April to June 2003. The density of the sea urchin *Anthocidaris crassipina* was very small and except for June 2003, was always less than 0.1 individual/100cm^2. In June 2003, its density was 0.14 individual/100cm^2. All the other herbivores were also low in density at <0.3 individual/100cm^2 all throughout the surveyed period.

Interactions between Algae & Herbivores

Results of Pair-wise Pearson Correlation showed that the cover of algae was not significantly correlated with the density of the herbivores (r = −0.112, $p > 0.05$, n = 15). For the results of Canonical Correlation, the first set was significant (p = 0.005) between the two pairs of canonical variates with encrusting algae having negative relationships with hermit crabs, the rock fish *Sebastiscus marmoratus* and small herbivores. The alga *Galaxaura oblongata*, in contrast, had positive relationship with these three types of herbivores. The contributions from *Galaxaura oblongata* and hermit crabs were more important than those from the other variables. The contribution from the sea urchin *Anthocidaris crassipina* was negligible.

Density and size of *Anthocidaris crassipina*

Comparing the density of *Anthocidaris crassipina* sampled over the years, albeit at times using slightly different methods, it can be observed that the number of these sea urchins was very low in 2000, ranging from 1.3 to 5.3 individuals/m^2, and remained low throughout 2003 to early 2004 (Fig. 3). The density, however, increased significantly by 2006. The mean density of *A. crassispina* increased from 5.5 individuals/m^2 in September 2006 to 10.23 individuals/m^2 in March 2007. In some quadrats, the density could be as high as 40 individuals/m^2. This increase in March 2007 was a result of recruitment of young urchins during winter (February and March). This is reflected in the population structures of *A. crassispina* shown in Fig. 4. In October 2006, 39 – 52% of the sea urchins were in the size range of 35 – 45 mm. In early 2007, the number of individuals having test diameter < 15mm increased to 21% in January and eventually to 32% in March (not all data shown). A more detailed analysis on changes in the size structure of *A. crassipina* in LLS, TPCMP is given in Li (2007). The mean density of *A. crassipina* remained high (> 5 individuals/m^2) in 2008-2009 (Fig. 3) with maximum density at 20 individuals/m^2

recorded in some quadrats.

Phenology of *Sargassum siliquastrum*

As typical for many *Sargassum* species, *siliquastrum* exhibits an annual cycle of growth and die-back. It has a slow growth period in spring to summer, a rapid growth period in the fall, cumulating in the peak reproductive period in early winter (December to January) before dying back in February to March. Over the years, this pattern has been consistent although the peak period of growth and reproduction may differ slightly from year to year (Fig. 3). Starting from September to October 2006, however, the population of *S. siliquastrum* failed to attain a rapid increase in length. By December 2006, the mean maximum length remained at only 13.4 ± 3.6 cm. In January and February 2007, only few reproductive plants were found. Although some increase in length was apparent in March to June 2007, this was largely due to development of the new shoots from the perennating holdfast. Thereafter, the population completely disappeared and in 2008 to 2009, no individual of *S. siliquastrum* was found in the same site (Fig. 3). The cover of *Sargassum* was reduced to 0%.

Discussion

Since our monitoring of the ecological condition of Tung Ping Chau in 1996, the presence of a large seaweed bed in LLS was a prominent feature. Although measurements of changes in the length of the *Sargassum* spp. in this bed were not carried out every year, their presence could not be missed. Our earlier data indicated that the growth cycles of the seaweeds, including the large *Sargassum* spp. were very regular for many years and herbivores were not an important structuring force in this seaweed bed. This situation, however, had changed dramatically since 2006.

Anthocidaris crassipina is a well known herbivore. Its grazing effect and changes in its population structure have been reported in other parts of Hong Kong (Chiu 1988) as well as in other parts of the Asia Pacific (Yoo *et al.*, 1982, Yatsuya & Nakahara 2004). It is a harvested resource in Hong Kong. Local villagers would collect these urchins in late winter for their gonads. Even small sizes of these urchins are collected, especially by fishers from mainland China, and grown in cages until a suitable marketable size for export (pers. com. with local villagers). This situation was also true in Tung Ping Chau in earlier years. On several occasions, we had directly observed the collection of these sea urchins by these fishers underwater as well as by the local villagers. Each time, the collection was very extensive and almost no urchin was left untouched.

Since Tung Ping Chau was designated as a marine park in November 2001, all forms of plant and animal collection are prohibited except with permission. Hook and line fishing is allowed but only in two designated sites. While local villagers could still collect the urchins for their local consumption, the large scale collection by other fishers is banned. Our pre-marine park data on sea urchin density clearly showed that the density was very low, and this density remained low in a few years (2003-2004) immediately after large scale collection of the sea urchins was banned. This low density population was likely maintained by harvesting pressure and it took a few years for the population to increase in size after harvesting was discontinued.

While no detailed monitoring on the density and sizes of *A. crassipina* was carried out between 2004 and 2006, our regular monitoring of the *Sargassum* bed within the same period did not find them to be prominent. This situation changed in 2006 when visual inspection of the seaweed bed showed the presence of many sea urchins. Our subsequent monitoring of their density confirmed our suspicion of the dramatic increase in their number. It is apparent that the banning of larger scale sea urchin collection after Tung Ping Chau was designated as a marine protected area may have contributed to the dramatic increase in the sea urchin populations. As observed, this high density of sea urchins grazed directly on *Sargassum* and was responsible for the decimation of the *Sargassum* bed.

The presence of this large *Sargassum* bed itself could have provided the food needed by the urchins for rapid population growth. The large recruitment in winter is timed with the presence of highest amount of seaweed biomass. The impact of sea

urchin grazing actually started in the shallower area of LLS. While individuals of *S. siliquastrum* could still be found in slightly deeper (-3 to -6 m CD) subtidal area, albeit in a much reduced size, individuals of *S. hemiphyllum* and *S. henslowianum* in lower intertidal and shallow subtidal were all gone as of October 2006. In other parts of TPCMP, like Lan Kwo Shui (LKS) and Lung Lin Tsui (LLT)

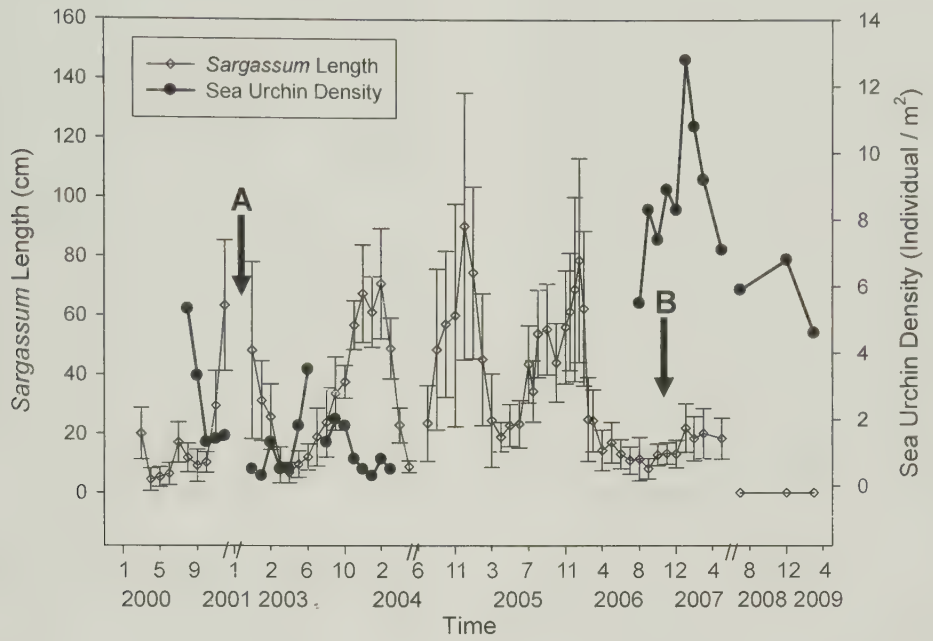

Fig. 3. Monthly mean length (± SD) of *Sargassum siliquastrum* from Lung Lok Shui, Tung Ping Chau Marine Park over a 10 year period from 2000 to 2009. Data on the density of the sea urchins *Anthocidaris crassipina*, when available, are also shown. Arrow A, time (Nov 21, 2001) when Tung Ping Chau was designated as a marine park. Arrow B, time (Nov/Dec 2006) when decimation of the *Sargassum* population started to become clear. Note time gaps in the X axis.

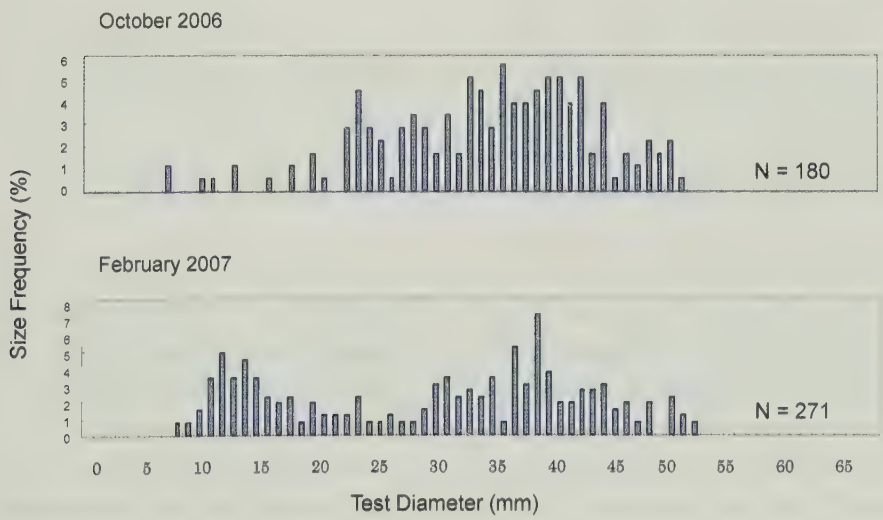

Fig. 4. Size frequency (%) of the test diameters of the sea urchins *Anthocidaris crassipina* in Tung Ping Chau Marine Park. Only data for October 2006 and February 2007 are shown to illustrate the increase in the number of small urchins in winter.

(see Fig. 1 for their locations in TPCMP), which are only a few hundred meters from LLS, large number of *Sargassum* spp. remained during this same period. A scenario could therefore be projected that this bloom of sea urchin population most likely started in the shallow area of LLS in 2006. There could be other environmental conditions that contributed to this bloom, e.g. warmer sea water temperature (?). But the most likely scenario would have been that the release of sea urchins from harvesting pressure, coupled with the absence of any large predators like fish and the presence of large amount of food in the seaweed bed, provided the impetus for its population expansion. This hypothesis could further be confirmed with other developments observed since 2006. The density of sea urchins remained high and in 2007 to 2008, these urchins had moved on to decimate deeper populations of *S. siliquastrum* in LLS, as well as populations of other *Sargassum* spp. in LKS and LLT. Extensive barren grounds can now be observed throughout the west and southwestern shore of Tung Ping Chau where large beds of *Sargassum* spp. used to stand. As of April 2009, pockets of *S. siliquastrum* could still be found in LLT. These populations are currently being monitored as they could serve as the source of recruits to the barren grounds should the population of *A. crassipina* decline in the near future.

Hong Kong fisheries are heavily overexploited so the absence of any large predatory fish is not a surprise. Elsewhere outside TPCMP (or in the earlier years in TPCMP), harvesting pressure itself serves as a top down control on the population of sea urchins, and indirectly on the seaweed populations. The question now is after the decimation of the seaweed bed in TPCMP, would the absence of food resource then provide a bottom up control that would eventually lead to the decline of the sea urchin population? Or would the persistence of sea urchins lead to a phase shift in the community structure such that barren grounds would become the norm rather than the exception?

One other indirect consequence of the formation of barren ground is the recruitment of other invertebrates, notably barnacles, on the newly opened space. The open areas cleared of *Sargassum* spp. in LLS are now all covered with barnacles. Would the dominance of barnacles prevent the coming back of the algae, and lead to further persistence of the barren ground even after the population of sea urchins has declined?

The formation of barren ground is an unexpected result of the protection of Tung Ping Chau as a marine park. This ran contrary to the very objective of the marine park designation, which is to preserve and protect the existing biodiversity, including the extensive *Sargassum* beds. Successful marine parks are expected to serve the functions of increasing the biodiversity and abundance of protected species, preservation of genetic pools, and eventual spill of individuals (adults, juveniles or propagules) to surrounding areas (Russ 2002). Our own studies, providing both temporal and spatial comparisons of the mean density and diversity of fish before and after Tung Ping Chau was designated as a marine park, indicated that there were increases in the fishery target species like the seagrass rabbitfish *Siganus canaliculatus*, as well as other species like the yellowstripe scad *Selaroides leptolepsis* and the silver sweeper *Pempheris schwenkii* (Tam & Ang in prep., Lam *et al.*, in prep.). None of these, however, are the predatory fish that could prey on the sea urchins.

In our survey of LLS in December 2008, some *Sargassum* individuals belonging to *S. hemiphyllum* and *S. henslowianum* had come back, mainly in the lower intertidal and shallow subtidal areas. However, the deeper areas remained barren with no sign of *S. siliquastrum*. Nonetheless, the return of *S. hemiphyllum* and *S. henslowianum*, albeit very few of them, may provide some hope on the potential of natural recovery of the *Sargassum* bed.

The unexpected formation of barren ground has implications for future management of TPCMP. Several critical management questions need to be addressed. In spite of the formation of barren grounds, should the system be left alone? Would large predators eventually appear in the marine park to initiate a top down control on the population of the sea urchins that would eventually lead to the recovery of the *Sargassum* bed? Or should human step in to act as the "top predator" under the unlikely scenario of natural appearance of other top predators? Finally, larger scale harvesting of

sea urchin is a more recent activity that probably started only in the last 20 or 30 years. There was no record of what the environment was like prior to that. Is it therefore likely that barren ground was actually the "natural" situation and seaweed beds appeared only because of the removal of these major grazers by human? How important is human harvesting pressure on sea urchins, or other herbivores like fish, contributing to the dynamics of the coastal algal community. What would be the other implications of this observed impact, i.e. on the role of seaweed bed as a nursery and breeding ground for other fish and invertebrates? All these questions inevitably point to the utility of setting up of the marine park itself and would need to be examined more carefully!

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Effects of recent ecological events on the distribution and growth of macroalgae in marine waters around Taiwan

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Abstract: Macroalgal resources are particularly abundant in the northeast coast and Hengchung Peninsula in the southern part of Taiwan as well as in several smaller islands around Taiwan. Classified as being in the tropical and subtropical areas, the diversity of macroalgal species and seasonal growth types are based on their geographical distributions in different coasts of Taiwan. During the past years, there were more than 600 species of macroalgae identified with certainty. Basically, tropical macroalgae are found in the eastern and southern parts of Taiwan, Shiao-Liou-Chou Island, Green Island, and Orchid Island. The subtropical macroalgae mainly occurred in the northeast coast of Taiwan. Mixed tropical and subtropical macroalgae can be found in the Pescadores, the three Northern Islands, and Kueishan Island. Besides geographical distribution, the Kuroshio and its branch currents also can affect the distribution of tropical macroalgal species. Some subtropical macroalgae, such as *Porphyra, Bangia,* and *Petalonia,* can only grow in cool areas washed by the cold current coming from the coast of Mainland China. Giant kelps, such as *Laminaria* and *Undaria,* cannot be found in Taiwan and offshore tropical islands, but some of them are cultured in Kinmen Islands and Matsu Islands off the coast of nearby Fujian province.

Recently, the macroalgal resources in Taiwan area have affected by global climate changes, coastal development, tourism, and environmental pollution. The species composition and cover of macroalgae in different coastal environments have changed as a result. For example, the mass proliferation of *Codium* species overgrows the hard corals in Nanwan Bay of Hengchung Peninsula. The diversity of corals decreased and the dominant benthos has phase-shifted from corals to macroalgae. In order to alleviate the situation, conservation organizations decided to increase the feeding pressure on the overgrowing macroalgae by prohibiting the harvest of herbivorous sea urchins from coral reefs. On the other hand, the coastal geomorphology of northeastern Taiwan was changed by several strong typhoons that struck during the past ten years. As a result, the harvest of some economic seaweeds such as *Porphyra, Gelidium, Eucheuma, Grateloupia* and so on declined dramatically. *Gelidium* harvest was also affected seriously by the release of herbivorous fish by some fishery groups. In February of 2008, a deep cold current was recorded in the Pescadores. The cold seawater caused more than ten thousand tons of fish to die. After this catastrophic event, studies have shown that macroalgae there grew more abundantly than ever before. It is obvious that recent ecological events have affected the normal distribution and growth of macroalgae around Taiwan and these phenomena should be further investigated

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Introduction

Benthic macroalgae are one of the most important biological resources in shallow marine ecosystems. They can support some of the most diverse and productive communities in the marine environment by performing the important role of primary producers. They also can provide the food and habitat for different generations of marine organisms. Recently, human activities, including agriculture, urbanization, and tourism have led to increased anthropogenic nutrient loading into shallow shores and caused these fragile ecosystems to shift to different phases. Nutrient enrichment was found to increase the biomass of macroalgae among these observed phase shifts, especially among some dominant and nuisance species (McClanahan *et al.*, 2007). Additionally, direct and indirect effects of overfishing activities may strongly affect biological interactions among coastal organisms, such as decreasing marine organism abundance, and changing population structures and distributions of certain species within the coral reef ecosystem (Hughes, 1994). Although macroalgal resources are particularly abundant in the northeast coast and Hengchung Peninsula in the southern part of Taiwan as well as in several smaller islands around Taiwan, the problems of overgrowing or degradation of macroalgal communities are rampant with serious consequences than conditions prevailing ten years ago (Dai, 1997; Tsia *et al.*, 2005).

Taiwan (21° 53' - 25° 18' N, 120° 1' -122° 0' E) is an island located in the western Pacific off East Asia with tropical and subtropical climates, because of being bisected by the Tropic of Cancer. There are some smaller islands around Taiwan, including the Pescadores Islands, Orchid Island, Green Island, and Shiao-Liou-Chou Island. The entire coastline stretches for 1,566.3 km around Taiwan. Oceanographic conditions around the islands vary with topography, water temperature, and current patterns. Macroalgae mainly occur on rocky shores in the northeastern and southern coasts as well as in other smaller islands. During the past years, there were more than 600 species of macroalgae identified with certainty in these areas (Chiang and Wang, 1987; Lewis and Norris 1987; Huang, 1990). Basically, tropical macroalgae are found in the eastern and southern parts of Taiwan, Shiao-Liou-Chou Island, Green Island, and Orchid Island. Subtropical species mainly occur along the northeast coast of Taiwan. Mixed tropical and subtropical macroalgae can be found in the Pescadores, the three Northern Islands, and Kueishan Island. Besides geological and topographical variations, water temperature and currents have also caused differences in macroalgal composition between the northern and southern parts of the Pescadores and Taiwan. The two main two currents affecting the coastal areas of Taiwan are the Kuroshio Current and the Mainland Coastal Current. The Kuroshio Current brings water of higher temperature and salinity up from the Philippines and the equatorial regions toward southern Taiwan where it branches into two. The stable, main branch with higher than 20 ℃ water temperature runs past the east coast of Taiwan where some tropical species are found. A smaller branch, subjected to seasonal variability, veers northwestward through the Taiwan Strait to the southern parts of the Pescadores. Flowing south along the Chinese mainland coastal region, the Mainland Coastal Current carries colder water from the East China Sea to the northern parts of Taiwan Strait, and is particularly strong in summer and less so in winter. Typhoons also occur disturbing the coastal areas every year and have caused considerable damages to marine ecosystems.

Some subtropical macroalgae, such as *Porphyra*, *Bangia*, and *Petalonia*, can grow in cooler areas washed by the cold current coming from the coast of Mainland China. On the other hand, tropical species such as *Halimeda* spp. can be found in the areas washed by the Kuroshio Current. Most of the macroalgae found in Taiwan exhibit obvious seasonal growth because of their annual characteristics. Macroalgae are most abundant from the end of winter to spring (about November to next May), and the plants disappear in the summer season. Giant kelps, such as *Laminaria* and *Undaria*, cannot be found in Taiwan and offshore tropical islands, but some of them are cultured in the Kinmen Islands and the Matsu Islands off the coast of nearby Fujian province across the Taiwan Strait. In Taiwan, the primary source of economic seaweeds has been

natural populations collected by coastal fishermen throughout the natural growing seasons. Therefore, the biomass and community structure of macroalgae are highly variable and impacted due to such activities (Wang and Chaing, 1994).

Recently, there were some serious ecological events that occurred in the coastal areas around Taiwan. The first major ecological event took place when the coral reef ecosystem in southern Taiwan exhibited a phase shift to macroalgae-dominated reef systems as a result of the combined effects of nutrient enrichment and herbivory reduction in Nanwan Bay, Kenting National Park. The second one happened in February, 2008 off the coasts of the Pescadores which were affected by a devastating deep cold current. Lots of herbivores and marine organisms died after this catastrophic event and the economic green seaweed *Monostroma latissimum* grew more abundantly than ever before due to the absence of its natural predators. Another case of interaction between macroalgae and herbivores was also observed in the northern coast of Taiwan. *Gelidium* harvest was affected seriously by the large-scale release of herbivorous fish (rabbit fish) by some fishery groups. This paper will cite these cases of macroalgae blooms and the close interactions between herbivores and seaweeds around Taiwan.

The mass proliferation of *Codium* in southern Taiwan

Coastal areas along Hengchun Peninsula in the southern part of Taiwan, which are among the most well developed coral reef ecosystems in Taiwan, have been subjected to increasing anthropogenic pressures resulting from expanded urban development and increasing tourism activities. Most nearshore reefs in Hengchun Peninsula, especially in Nanwan Bay (21° 57' N, 120° 44' E), are characterized by high abundance of fleshy macroalgae and low abundance in herbivorous fishes (Dai, 1997). These algal blooms in Nanwan Bay are often dominated by opportunistic algae in the genera *Ulva, Codium, Laurencia,* and *Sargassum*. Decreases in species numbers, colony numbers, reef coverage, and species diversity of corals were observed in Nanwan Bay from 1987 to 1997 (Dai *et al.*, 1998). It is well known

Fig. 1. The mass proliferation of *Codium edule* in southern Taiwan

that the shift of coral reefs to algae-dominated reefs generally causes a dramatic decline in fish stocks and biodiversity in coral reef ecosystems (NRC, 2000). Thus, an understanding of macroalgal abundance on southern Taiwan coral reefs is an important aspect of the ecological, environmental, aesthetic and socio-economic value of the reefs.

Codium edule (Fig. 1) is the most abundant species among nuisance macroalgae in Nanwan Bay of southern Taiwan (Chiang and Wang, 1987; Dai, 1997). A specialized organ that acts as a proliferative propagule is often issued from the side of utricles at the end of the growth season. Juvenile filaments were sprouted out from these propagules and formed new utricles after laboratory culture of 10-14 days. The new utricle and filament were divided by a septum and propagules showed the ability to eventually develop into a new thallus. We suggested that the propagule buds are possibly transformed gametangia showing incomplete meiosis as shown by nucleus staining experiments. The propagule buds may serve as a persistent stage when the macrothalli disintegrate at the end of the growing season, and act as a "seed bank" for vegetative reproduction for *C. edule* into the next season (Chang, *et al.*, 2004). A new pathway within the *C. edule* life cycle has been proposed by Chang (2002, see Fig. 2).

Besides the opportunistic asexual stage of *Codium edule* as one of the main reasons for its mass proliferation in Nanwan Bay, the decline of herbivores brought about by overfishing has been identified as another important factor causing the shift of coral reefs to algal dominated systems causing a dramatic decline in the biodiversity and altering ecological dynamics in the reef ecosystem (Liu *et al.*, 2009). In order to alleviate the situation, conservation organizations decided to increase the feeding pressure on the overgrowing macroalgae by prohibiting the harvest of herbivorous sea urchins (such as *Tripneustes gratilla*) from coral reefs. At present, the number of sea urchins has slowly increased from about 8 to 13 / m^2 while the species number of coral fish has also increased from 31 to 110. Thus, a thorough understanding of the macroalgal population dynamics can be considered

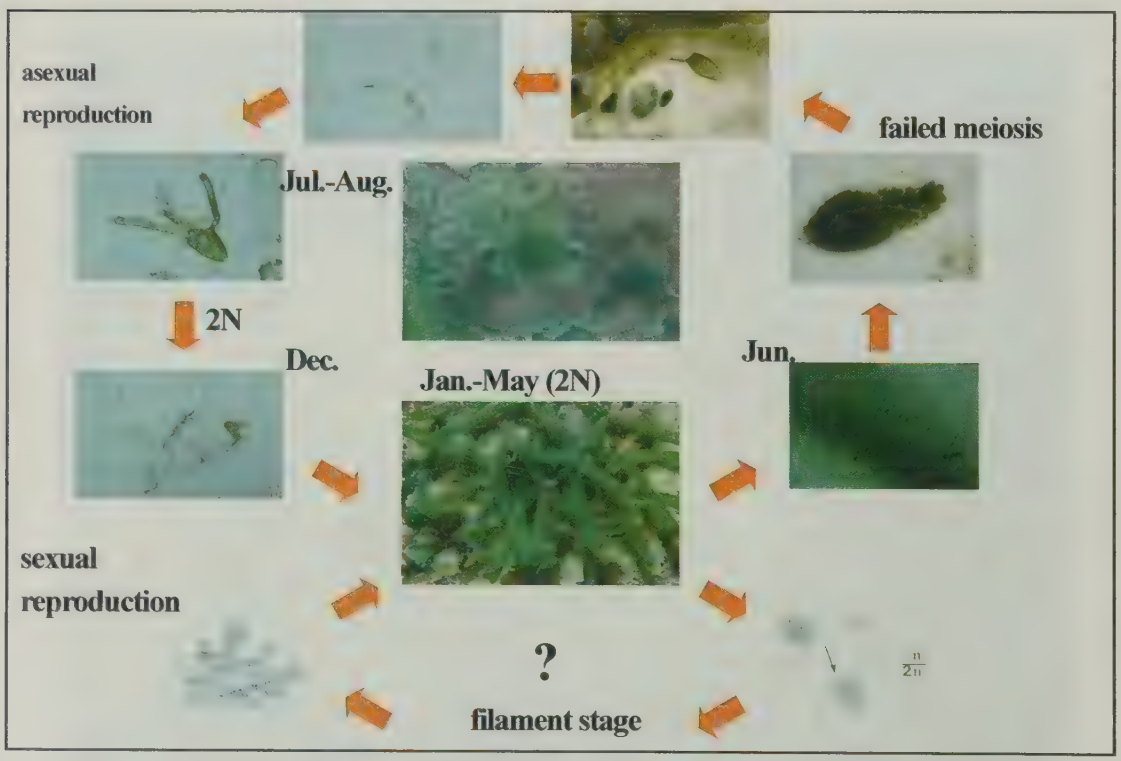

Fig. 2. The stage of asexual reproduction by propagation buds transforming from immature gametangia in the life cycle of *Codium eduleof* southern Taiwan.

to be an important aspect of the ecological, environmental, aesthetic and socio-economic value of reefs.

The interactions between macroalgae and herbivores as affected by environmental change

The coastal geomorphology of northeastern Taiwan has been changed by several strong typhoons that struck during the past ten years. As a result, the harvest of some economic red macroalgae such as *Porphyra*, *Gelidium*, *Eucheuma*, *Grateloupia* and so on declined significantly. However, the impact of herbivores on macroalgal populations can be as devastating as the effects of typhoons. Besides sea urchins, rabbit fish is another well known herbivorous organism in the tropical Pacific waters. It is captured and sometimes cultured for its economic value as a food fish. It was chosen as one of the introduced species to supplement the existing coastal fishery resources by fishery groups in Taiwan and subsequently released into the wild (Fig. 3). During the past three years, *Gelidium* harvest was not only affected seriously by destructive typhoons, but also adversely affected by the intentional release of herbivorous fish by some fishery groups. This unfortunate intervention to release introduced fish for a good purpose should have been carefully evaluated prior to its implementation taking into account the close interaction between macroalgae and herbivores and some long term effects on the marine ecosystem as a whole. Species introductions generally have far reaching ecological consequences whose impacts do not surface until several years thereafter.

In February of 2008, a deep cold current was recorded in the Pescadores. The cold seawater caused more than ten thousand tons of fish to die. After this catastrophic event, studies have shown that macroalgae grew more abundantly than before, especially the economic species, *Monostroma latissimum* (Fig. 4). It was supposed that lots of herbivores died after the cold current occurred, causing a major shift in the natural herbivore-macroalgal equilibrium. Although the value and harvest of this edible alga in 2009 was the

Fig. 3. The mature rabbit fish being the dominant species and feeding on the macroalgae (especially on *Gelidium*) in northeast coast of Taiwan. (Photo by Dr. LiSu Chen)

highest seen during the past 15 years, the impact of the cold current on the other coastal fishery resources are only starting to be felt. Hopefully the slow recovery of affected marine resources stock should be on the horizon, with coastal fishery managers learning from this experience to devise new and relevant marine coastal resource management strategies.

Conclusion

The Isoyake phenomenon in Japan is one example that showcases the effects of changing environmental conditions on macroalgal communities. Similar phenomena around the world, particularly in the western Pacific Ocean have been documented. In Taiwan as well as in neighboring countries, drastic decrease or increase of macroalgal populations have been attributed to some environmental factors, such as global climatic change, seawater warming, or increase in dissolved nutrients discharges among other factors. The change in herbivore population is also emerging as an important factor that tends to upset the balance of trophodynamics in benthic ecosystems and drastically altering the structure of complex marine food webs. The documented cases in Taiwan are only beginning to be understood and much further research is necessary. We hope some key points of the dynamics of macroalgal blooms or their population decline in coastal ecosystems can be explained and eventually some effective strategies for coastal management can be proposed in a timely fashion while the marine environments continue to change in the future.

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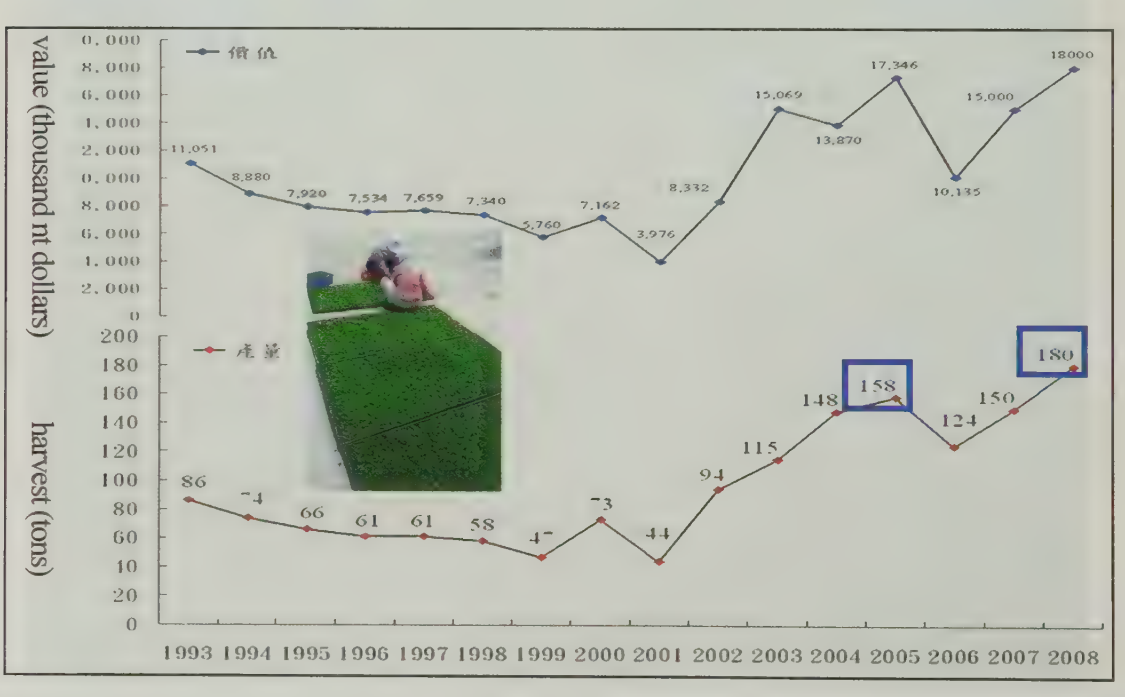

Fig. 4. The harvest and value of *Monostroma latissimum* from 1993 to 2008, especially while a abnormal lower seawater temperature made lots of herbivores died in Fabruary, 2008. (data from Fishery Annual Report, 2008)

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Artificial enhancement of sea-forest for reducing the Isoyake degree along the north coast of China

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Abstract: Sea-forest plays an important role in offshore biological production, remediating marine ecological environment and recruitments of fishery resources, etc. With the influence of marine environment, over exploration, global climate change, sea-forest resources are seriously reduced in the northern coast of China. Artificial reefs play important roles in retorting the sea-forest and coastal ecosystem. From 2006, the local government initiated projects with input of about 160 M RMB for artificial reef construction for the enhancement of shallow natural resources and for Isoyake alleviation along the coast of Shandong Peninsula (Weihai, Yantai, Rongcheng, Qingdao etc). With establishment of ten artificial reef sites for the sea-forest enhancements, they aim to construct 3000 ht sea-forests along the local coast areas, and the economic and ecological effects of artificial reef were evaluated ideal after the construction. Here, the present situation of artificial reef construction was summarized and introduced, and existed problems were either pointed out. In addition, the implementation of artificial reef and the continuous development were discussed, either the assessments of effects of artificial enhancement were mentioned.

Key words: sea-forest, artificial reef; colonization

Introduction

Sea-forest formed by macroalgae on rocky bottoms has been recognized to be significant in ecological and biological function. It provides a habitat for fish and shrimp spawning-beds, breeding and feeding grounds for coastal fish and shellfish, as well as for other important fisheries enhancement (Largo and Ohno 1993, Terawaki *et al.*, 2001). In order to achieve sustainable coastal development, protecting sea-forest has been emphasized as one method to conserve a healthy coastal environment and marine resources (Choi 2000). Usually, "Isoyake" areas become to "deforestation" in sea-water environments, which mainly caused by intensive grazing by herbivorous animals (Harrold and Pearse 1987). During the process of sea-forest's rehabilitation, the artificial algal reefs provide the places for seaweed attachment to form the alga superiority population within the short time (Falace and Bressan 2002, Ohno *et al.*, 1990).

Artificial reef is a kind of artificial facility which is used to build marine ranch, control and optimize marine ecological environment and proliferate biological resource. It has been used for over 200 years to enhance fishery resources (Baien 2001, Lewis and MaKee 1989, Tsumura *et al.*, 1999). The design of artificial algal reefs is an important and complex, and the shape and material of reefs influence recovery of sea-forest (Grigg 1994, Zhang *et al.*, 2008). Historically, the Japanese conducted the inventive works on artificial reef construction from 1950's, with the effective deploring of the artificial reef, it increased of output and quality of fish catches (Mottet 1985).

Comparatively, the present sea-forest destruction (Isoyake) along the north coast of China is serious, and it may ascribe from the deterioration of coastal environment and the possible global climate change effects. The implementation of artificial reef was

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started from 1970's (Zhang and Sun 2001), even though the preliminary works carried out and needs improvements, the yielded results are positive. So far, attentions were paid by both the governments and companies, and more input will be put in the future.

Here in this paper, the artificial reef project of Shandong and the problems of artificial reef building in China were reviewed and summarized.

The implementation of artificial reef project in Shandong peninsula

In China, fishery resources has declined rapidly for many reasons from the last seventies. Over 30,000 tons of shrimp production were obtained annually in Shandong coastal areas, but now reduced to merely 1,000 tons in recent ten years. Except to the controlling of over exploration and fishery catch, artificial reefs are considered as an important method to solve these problems, because it will enhance the shallow natural resources and remediate the coastal ecosystem. From 2005, the local provincial government initiated one project with about 160M RMB for artificial reef building for Isoyake alleviation along the coast of Shandong Peninsula (Weihai, Yantai, Rongcheng, Qingdao etc, Fig.1.), so far, eleven artificial reef sites were established for the sea-forest enhancements, with total of 3000 ht sea-forests implementation locally.

Before 1980's, the construction of artificial alga reefs was extensive, simply put the worn ships and blocks into the sea directly. In recent years, the design of reefs developed to intensify effects locally north coasts of China. The concrete was the most commonly used material during the construction of reefs, and the coal ash, steel, the shell, the lumber were either applied. Reefs of various shape reefs

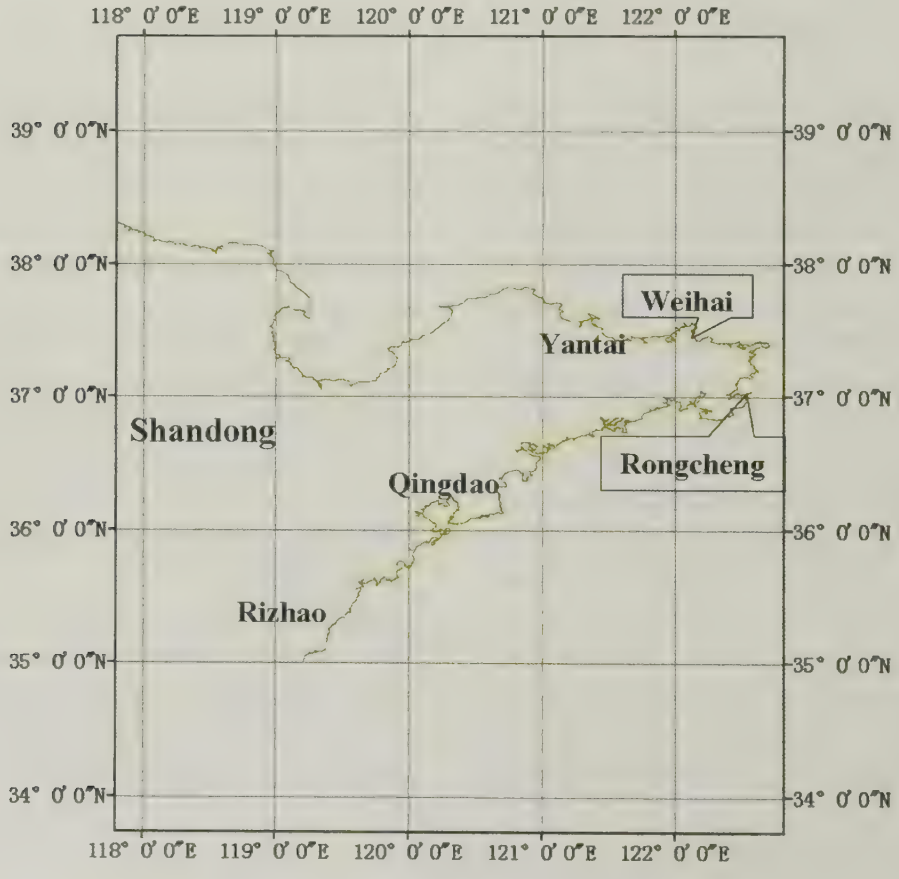

Fig. 1. Layout of artificial reefs in Shandong.

were constructed (Fig.2.) and the surface was concave-convex and the superficial and internal was vesicular structure, with aim to enhance the seaweed attachment easy and promote growth. After the implementation, fish and shellfish increased obviously. Through the 3 years rehabilitations and efforts, the marine biodiversities increased (fish, sea cucumber, shrimp, crab etc, Fig.3.) obviously, and the reduction of fishery were relieved, and the serious degree was prevented. For examples, the fishery catch in deep artificial reefs areas in Weihai is 15-20 times of that in other areas, and it

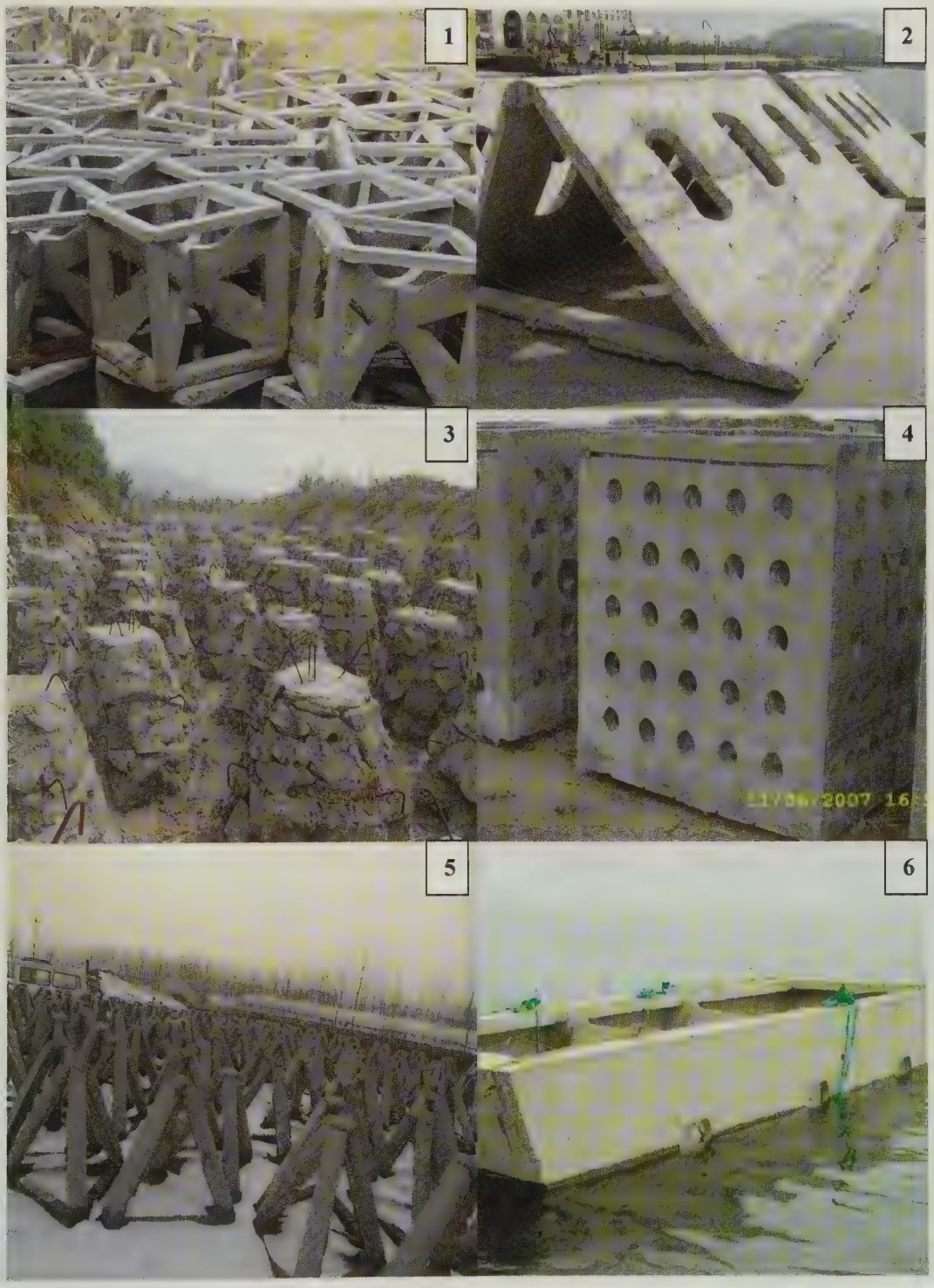

Fig. 2. 1-6 Various types of concrete reefs applied in north coasts of China.

is estimated that the fishery products increased 225 tons with 3039 x 10^1 RMB, and the estimated the fishery production is 1446 tons.

The problems of artificial reef building and study in north China

1. Quantitive investigation and survey for the degree of Isoyake and rehabilitations needs to be carried out, so far, the situation of Isoyake along the north China coast is not clear yet. Therefore, it needs to evaluate and optimize the design and construction of artificial reefs, because there are relationships between the marine ecosystem and deplored artificial reefs.

2. So far, there isn' t a system for the criterion of artificial reefs in north coasts of China, it needs to construct one typical coastal system or pattern for the evaluation of the enhancement. Moreover, filed study and survey should be carried out for evaluation of the effects of the work.

3. New materials for artificial reefs construction are found for more durable and low cost purpose. Figure optimization of artificial reefs should be conducted, and the sites selection for the artificial reefs should either be evaluated before and after the action.

4. There are many factors for the consideration before artificial reef construction, such as, position selection, material and style, the style of deposition

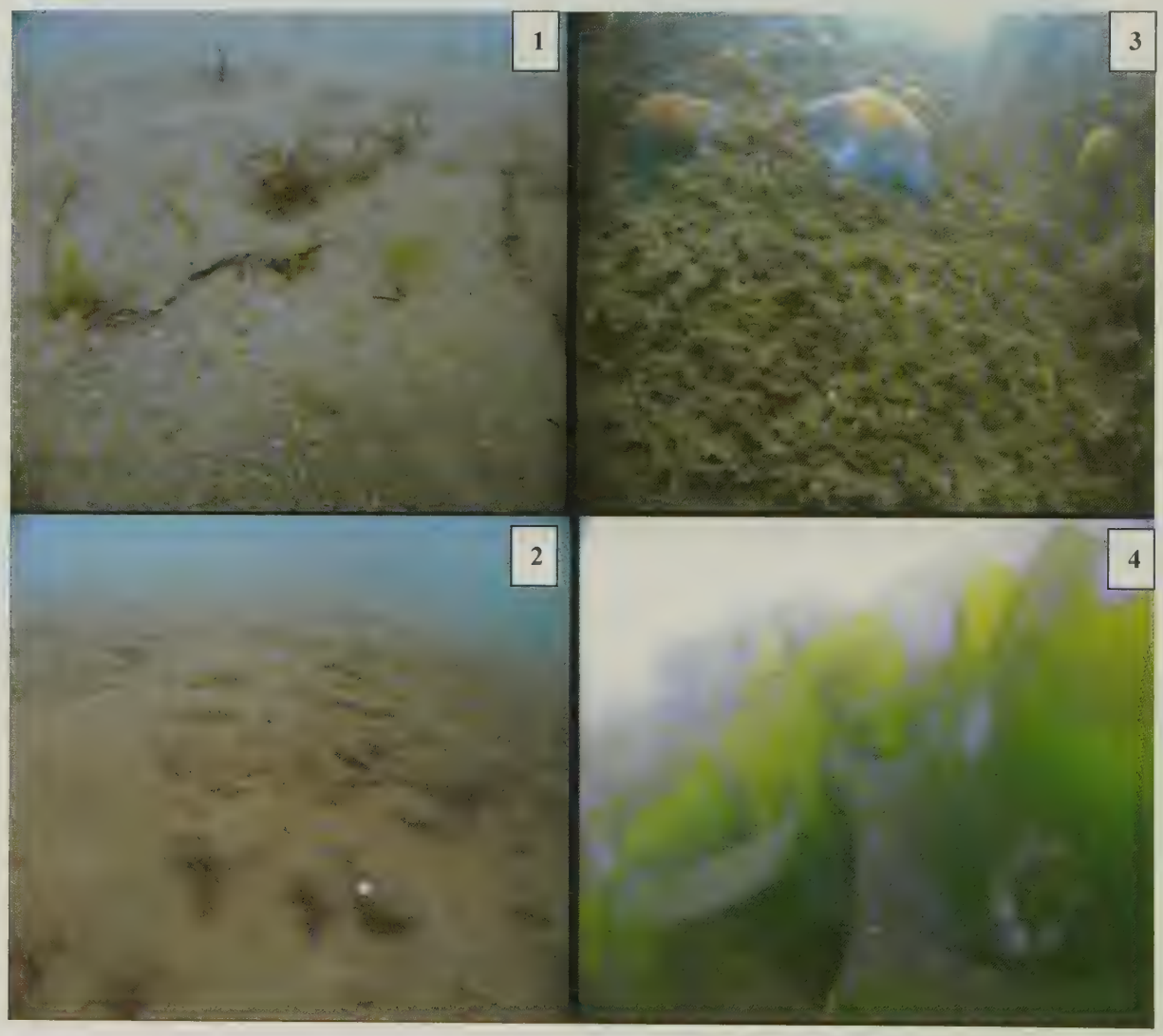

Fig. 3. 1-2 Before artificial reef construction, 3-4 After artificial reef construction.

and arrangement, the species of fishery resources in deposited area, weather conditions, the situation of sea floor, etc.

5. So far, there are no legislations to protect the construction of artificial reefs, it needs to draft the chapters or legislation formula for the effective protection of artificial reefs and eventually to the coastal bioresources.

6. Even though the support of government for the implementation of the work, it needs to continuously to support the work with the long plan.

Summery

Sea-forest is a common habitat in coastal inshore ecosystems. Macroalgae provide primary productivity to biological communities and provide the food web. Macroalgae offer ideal habitats for many plants and animals in coastal ecosystem. These beds provide spawning and feeding grounds for fish or shrimp, and refuges for many fish species as well as micro and macro aquatic organisms (Komatsu and Tatsukawa 1999). Artificial reef can provide the places for macroalgal attachment to rebuild sea-forest in a short term.

So far, many artificial reefs were built and studied both in China, and it showed the ecological and economic profit in many coastal regions in China. Comparing with the technology of advanced countries, there is still improvements and continues hard work for artificial reefs construction in China. Only in this way, we can reach the goal for the improvement of coastal or marine environment and the enhancement of marine resources.

It is urging for the government to enlarge the investment for investigation and survey of coastal system and for improvement of marine environment, to bring the attention of public awareness of sea-forest role and importance.

Acknowledgment

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A review of destruction of seaweed habitats along the coast of the Korean Peninsula and its consequences

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Abstract: Large seaweeds can form dense underwater forests. These forests provide a physical structure that supports marine communities by providing animals with food and shelter. Until the end of 1980, *Sargassum*, *Laminaria* and *Ecklonia* forests were abundant all along the Korean Peninsula except the coastal zone of the Yellow Sea where the sea bottom is composed of mud. From the beginning of 1990s, however, these forests had been decreasing due to various reasons such as global warming, sea urchin grazing, industrialization near the shores, and over releasing of abalone without consideration of carrying capacity of rocky habitats, and by the end of 2004, ca. 13% of the East Sea and 31.4% of Jeju island in the South Sea became barren ground with crusty pink algae and little else covering the rocks. Construction of artificial seaweed beds, therefore, is presently looked into as a necessary factor for the recovery of natural resources. Of the seaweed species, *Sargassum*, *Laminaria* and *Ecklonia* are of interest in Korea. Various techniques have been applied to construct artificial seaweed beds. This paper reviews the extent of destruction of seaweed habitats along the Korean Peninsula and several techniques applied to construct artificial seaweed beds in Korea.

Key words: Barren grounds, Seaweeds, Artificial reefs, Korea

Introduction

The Korean Peninsula is surrounded by the East Sea on the east, the South Sea to the south, and the Yellow Sea to the west and influenced by the two main currents, the Tsushima Warm Current and the North Korea Cold Current. Since the northern part of the East Sea above 38° N is strongly affected by the North Korea Cold Current flowing southward along the northeast coast of the Korean Peninsula, boreal seaweed species such as *Costaria*, *Laminaria*, and *Coccophora* are abundant. In contrast, since the southern part of the East Sea between 36 and 38°N is affected by both the East Korea Warm Current branching off from the Tsushima Warm Current at the eastern end of the Korea Strait and the North Korea Cold Current, temperate seaweed species such as *Undaria*, *Sargassum*, and *Pachymeniopsis* are abundant. In both the northern and southern part of the East Sea, however, coastal lines are mostly composed of sand beaches and, thus, seaweeds species are found only in shallow exposed rocky areas. Since the South Sea including Jeju Island which is located at the southeastern most of the Korean Peninsula is strongly affected by the Tsushima Warm Current and coastal lines are mostly composed of sandstones and conglomerate outcrops, temperate seaweed species such as *Undaria*, *Ecklonia*, and *Sargassum* form dense subtidal algal forests. In contrast, the costal line of the Yellow Sea is mostly covered by mud or sand and few seaweed species can survive. The destruction of seaweed habitats, therefore, is mainly occurred along the coastal line of the South and East Sea. Particularly, rocky habitats in the southern part of the East Sea (i.e., the eastern part of Gangwon, Gyeongbuk and Gyeongnam province) and Jeju Island, where fishing villages are well organized

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and release diverse marine organisms (e.g., abalone) to enhance fish production, are widely suffering the destruction of seaweed habitats (Fig. 1)

Areas of barren ground

The ecological and economical problem related to the destruction of seaweed habitats (i.e., barren ground) began to be issued from the end of 1980's, but surveys on the distribution of barren grounds started in 1997 due to the lack of research funding. Until 1997, barren grounds were found only in Gangwon and Gyeongbuk province and the percent of barren grounds to total rocky habitats in these two provinces was less than 2.6% (Table 1). In 1998, however, barren grounds spread into Gyeongnam and Jeju province and the percent of barren grounds to total rocky habitats in Gangwon, Gyeongbuk, Gyeongnam and Jeju province was more than 7.7%. In 2004 when the survey was stopped, the area of barren ground in Gyeongbuk and compared to 1998, whereas that in Gangwon and Jeju province was slight increased as compared to 1998. The percent of barren grounds to total rocky habitats of Gangwon, Gyeongbuk, Gyeongnam and Jeju province was 8.3, 15.6, 17.1 and 31.4%, respectively.

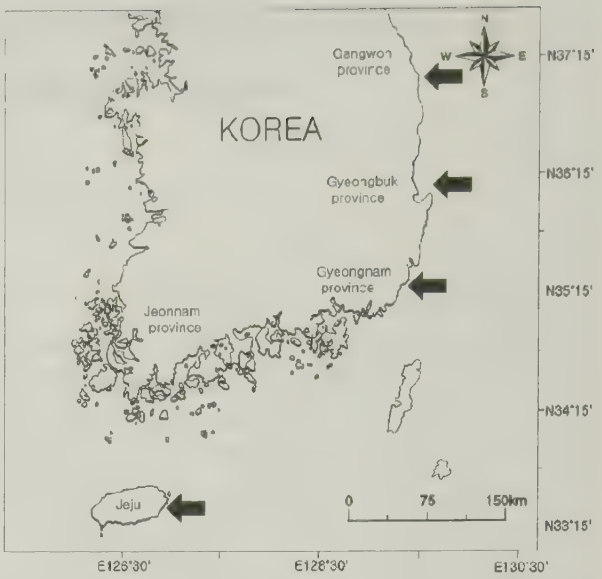

Fig. 1. Map showing the area suffering the destruction of seaweed habitats in Korea.

Reduction of fish production

Fig. 2 shows the yearly changes in the production of commercial animal species (i.e., *Nordotis discus, Sulculus diversicolor supertexta, Turbo* (*Batilus*)

Table 1. Yearly changes in the percent of barren grounds to total rocky habitats (from NFRDI, 2007)

Province	City name	Area (ha)	Year									
			1997		1998		1999		2001		2004	
			ha	%	ha	%	ha	%	ha	%	ha	%
Gangwon	Goseong	3489	0	0	0	0	20	0.6			48	1
	Sokcho	551	0	0	60	10.98	10	1.8			15	2.7
	Yangyang	1854	0	0	62	3.3	2	0.1			26	1.4
	Gangneung	2890	0	0	15	0.5	15	0.5			118	4.3
	Donghae	573	0	0	206	36	206	36			182	31.8
	Samcheok	1859	155	8.3	523	28.1	523	28.1			540	29.1
	subtotal	11216	155	1.4	866	7.7	776	6.9			929	8.3
Gyeongbuk	Ulju	2730	112	4.1	190	7	179	6.9			340	12.4
	Ulleung	793	0	0	134	16.9	134	16.9			102	12.9
	Yeongdeok	1372	20	1.5	99	7.2	95	6.9			225	16.4
	Pohang	2973	83	2.8	1106	37.2	1106	37.2			571	19.2
	Gyeongju	554	0	0	13	2.3	260	47			73	13.2
	subtotal	8422	215	2.6	1542	18.3	1774	21.1			1311	15.6
Gyeongnam	Ulsan	1012			366	36.26	336	33.2			173	17.1
	subtotal	1012			366	36.2	336	33.2			173	17.1
Jeju	Jeju	646			36	0.2			36	0.2	244	1.7
	North Jeju	7113			738	5.1			591	4.1	1750	12.1
	Seoguipo	1661			598	4.1			598	4.1	741	5.1
	South Jeju	5031			1559	10.8			1308	9.1	1806	12.5
	subtotal	14451			2931	20.3			2533	17.5	4541	31.4
Total		55751	740	1.8			5436	13.5	2533	17.5	9367	16.8

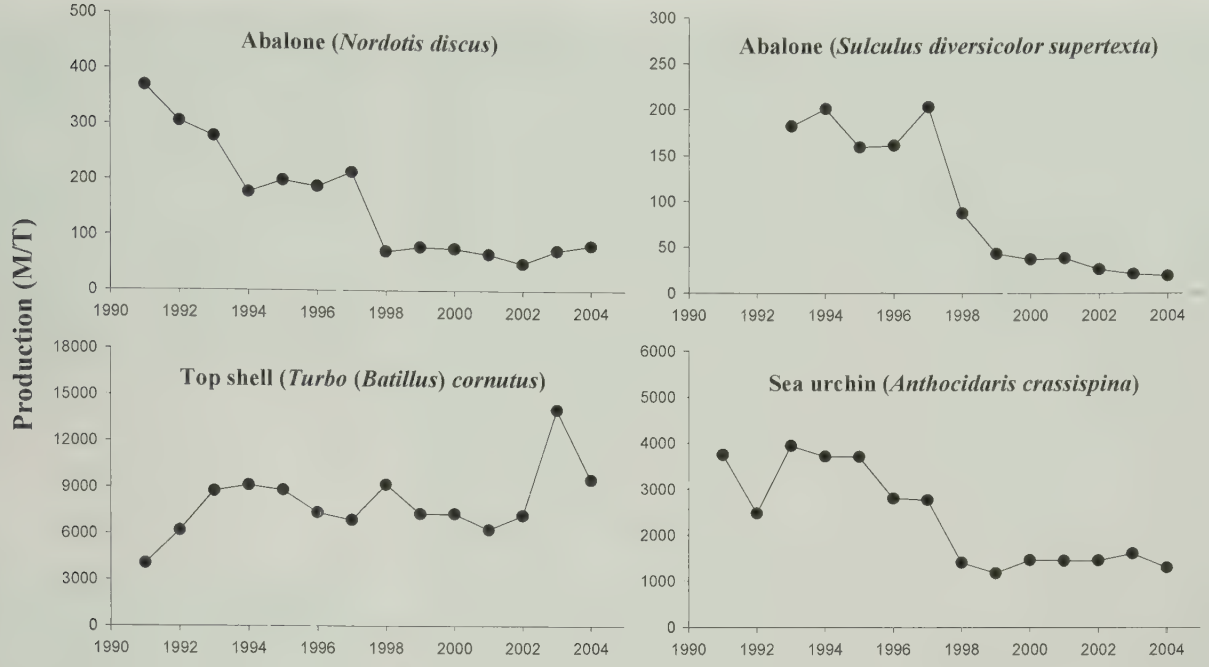

Fig. 2. Yearly changes in the production of commercial animal species living in rocky habitats during 1991 to 2005 (from Ministry of Land, Transport and Maritime Affairs, 1991-2005).

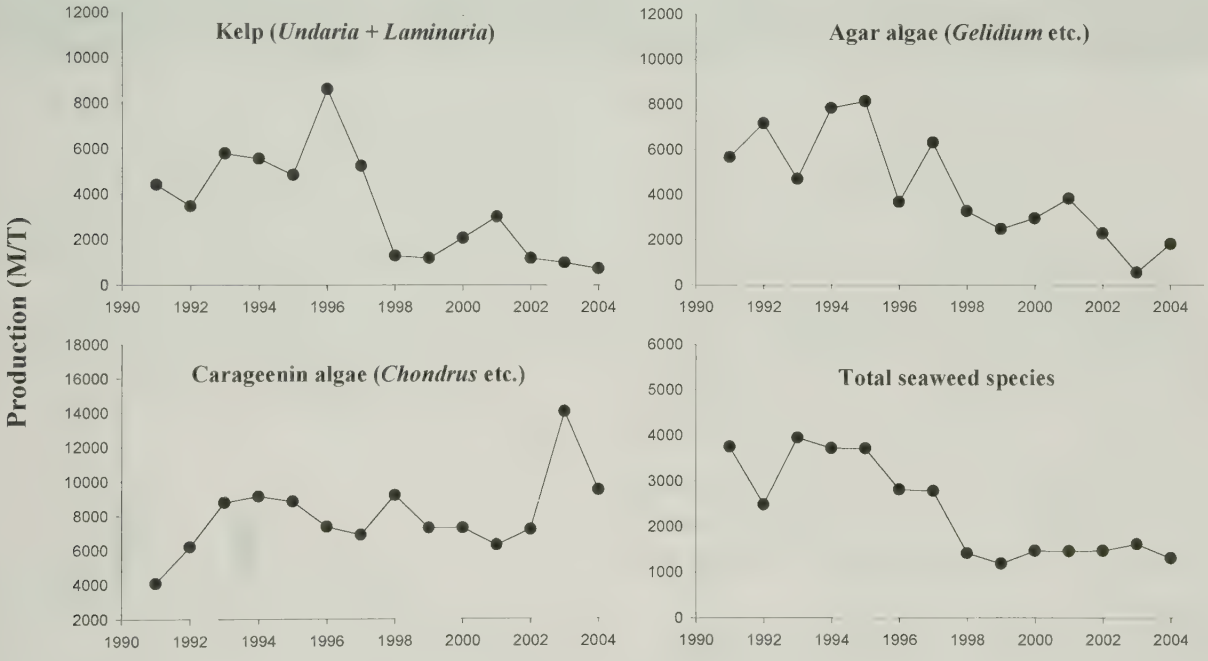

Fig. 3. Yearly changes in the production of commercial seaweed species during 1991 to 2005 (from Ministry of Land, Transport and Maritime Affairs, 1991-2005).

cornutus and *Anthocidaris crassispina*) living in rocky habitats during 1991 to 2005. Except top shell *Turbo* (*Batilus*) *cornutus*, the production of the animal species sharply decreased from 1997 in accordance to the increment of barren grounds. Likewise, the production of seaweed species sharply decreased from 1997 in accordance to the increment of barren grounds (Fig. 3).

Causality of destruction of seaweed habitats

Probably, a lot of biotic and abiotic factors have

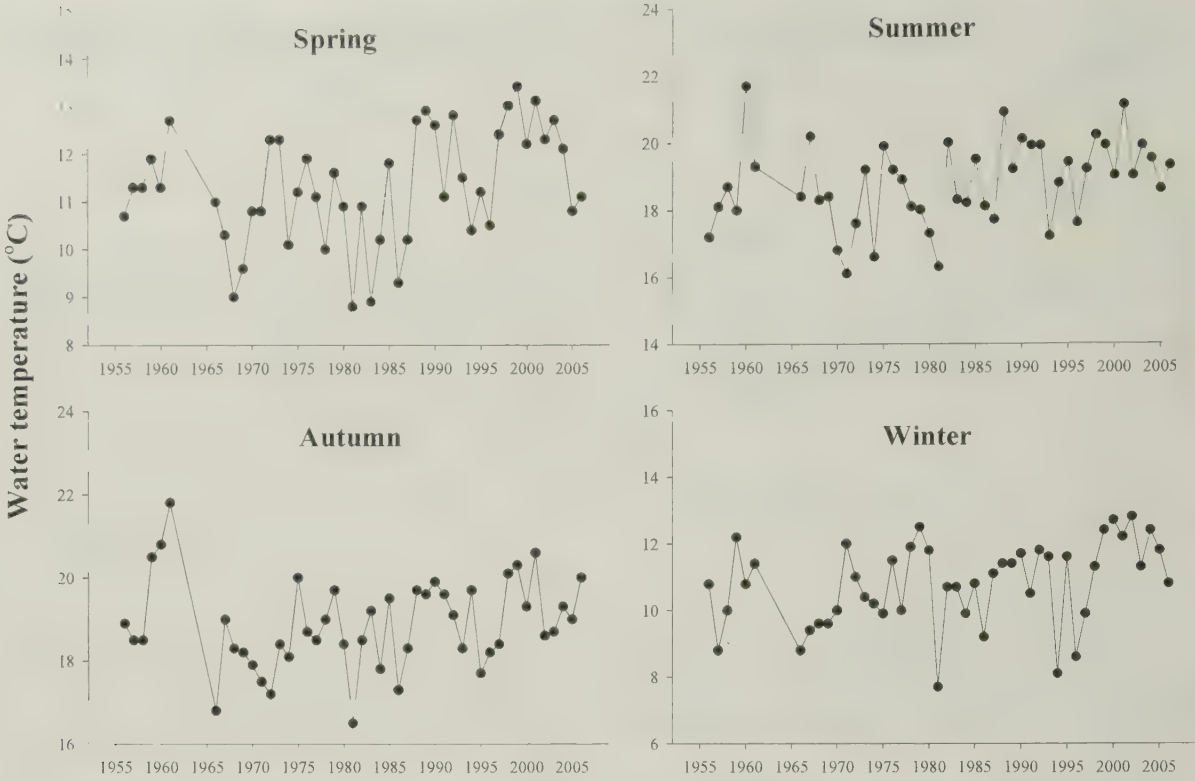

Fig. 4. Yearly changes in seawater temperature of the coast of Uljin city in Gyeongbuk province during the period from 1955 to 2005.

affected seaweed communities, causing barren grounds. These factors are likely to be global warming, industrialization near the shore, sea urchin grazing, and over releasing of abalone without consideration of carrying capacity of rocky habitats. For example, Fig. 4 shows the yearly change in seawater temperature of the coast of Uljin city in Gyeongbuk province where 12.4% of rocky habitats was changed to barren ground in 2004 (please see Table 1). During the period from 1955 to 2005, seawater temperature was apparently increasing, suggesting that global warming is a key factor causing barren grounds in this area. In addition, some coastal zone of Uljin city is also affected by thermal pollution caused by the discharge of the Uljin Nuclear Power Plant. Surveys on 12 fishing villages adjacent to the power plant indicate that species diversity and biomass of seaweed communities of the 12 villages are apparently lower than those of the control (ca. 30 km away from the power plant) and that some villages near the power plant are clearly changed to barren grounds, suggesting that industrialization near the shore is also important in the destruction of seaweed beds (Figs. 5, 6). Furthermore, over releasing of abalone without consideration of carrying capacity of rocky habitats is a problem in this area. Fig. 7 shows the number of juvenile abalones released into Korean

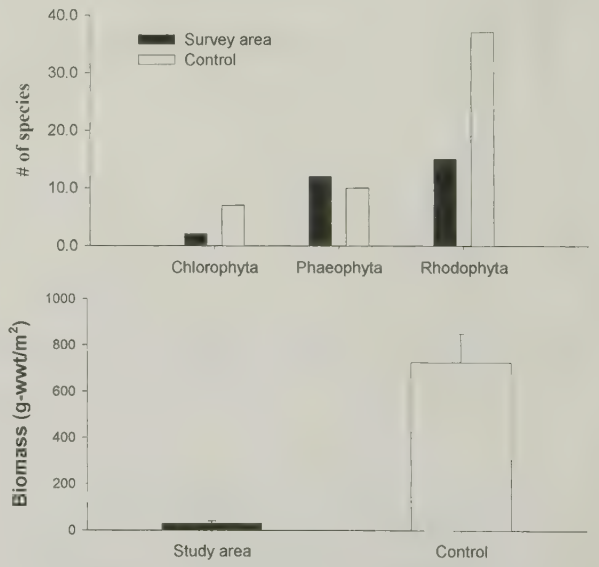

Fig. 5. Comparisons of species diversity and biomass between 12 fishing villages adjacent to the Uljin Nuclear Power Plant and the control located ca. 30 km away from the power plant.

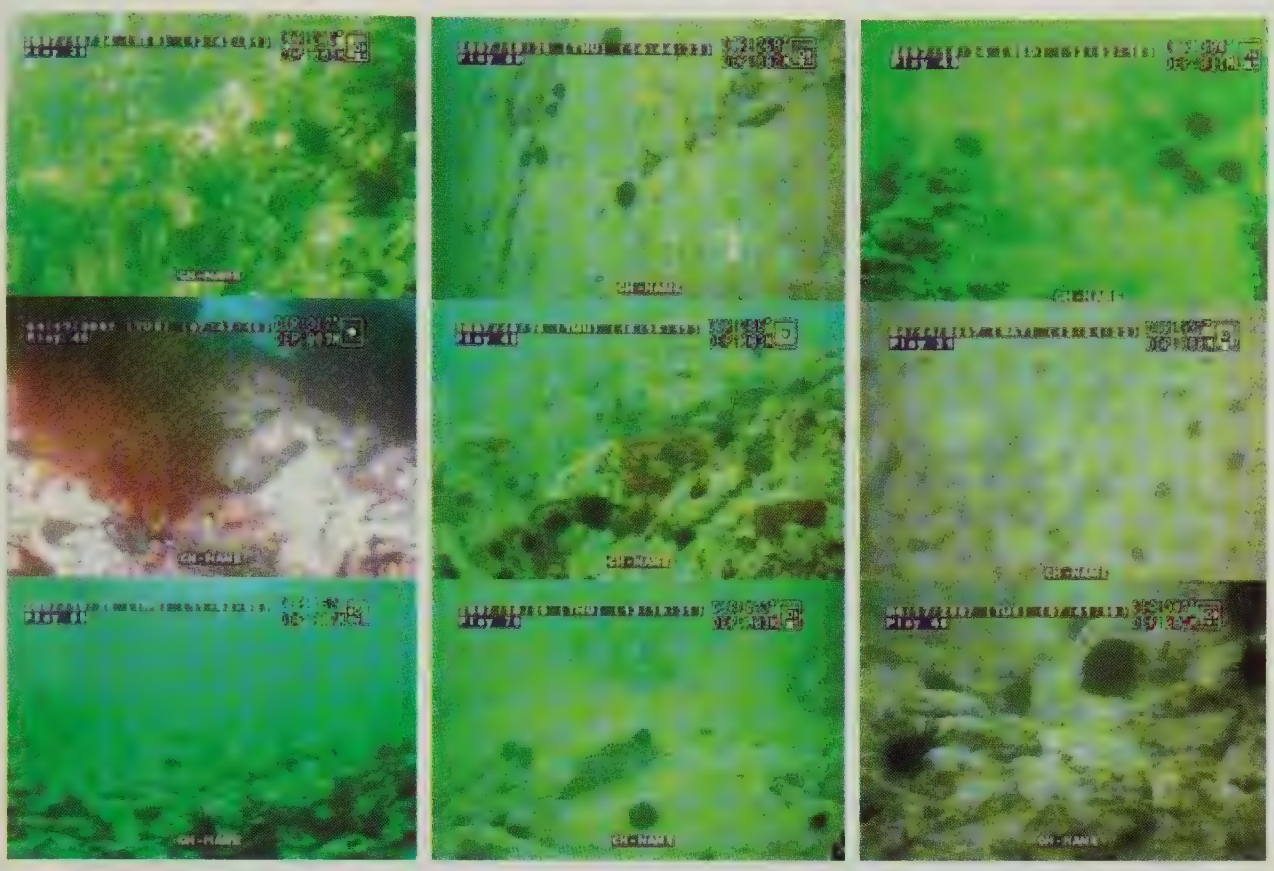

Fig. 6. Barren ground on subtidal zones of some fishing villages near the the Uljin Nuclear Power Plant.

waters during the period from 1996 to 2005. The number of released juvenile abalones explosively increased between 1999 and 2005, and this is also true for Uljin city including the 12 fishing villages. Taken together, changes in seawater temperature, the effect of thermal pollution and over releasing of abalone are all important factors destructing seaweed beds along the coast of Uljin city.

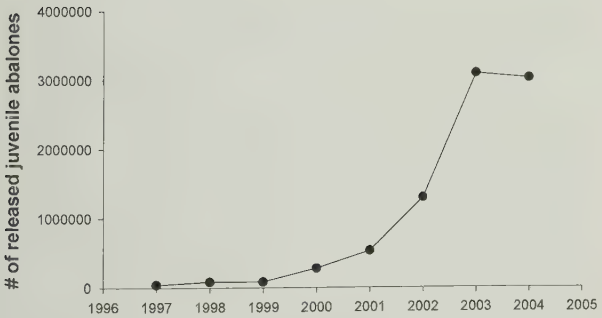

Fig. 7. The number of juvenile abalones released into Korean waters during the period from 1996 to 2005 (from Ministry of Land, Transport and Maritime Affairs, 1996-2004).

Construction of artificial seaweed beds

Korea's interest in artificial seaweed beds began at the end of 1990's and several techniques for constructing artificial seaweed beds have been applied (Figs. 8, 9). Some of these techniques are relevant to the recovery of damaged seaweed beds but others are not in terms of persistence or environmental-friendly purpose.

1. Spore-bag technique

The spore-bags packed with fertile, adult plants are usually suspended over rocky substrata or artificial reefs during the reproductive season (Fig. 8A-D). During this time, spores are released naturally and eventually settle on the hard bottom surface. This method has proven to be a successful method for the establishment of *Sargassum* beds.

2. Rope-seeding technique

Fertile thalli of *Laminaria* may be allowed to

Fig. 8. Construction of artificial seaweed beds (A-D: spore-bag technique, E-G, Q: rope-seeding technique, H-P, R-T: adult-plant transplantation method (from Kim, 2006).

sporulate in indoor tanks. Once ropes are seeded, the seeded ropes are then firmly attached to concrete blocks for growing (Fig. 8E-G, Q).

3. Adult-plant transplantation method

Fully reproductive adult *Ecklonia* are transplanted in September to December (Fig. 8H-P, R-T). One or two adult individuals can be attached to concrete blocks with strong rubber bands or ropes. In some cases, to increase the area of the attachment surface, the concrete blocks may be covered with coils of plastic material. Whichever case is used the plants are then covered with plastic sheets or placed in large cages for protection against fish grazing. The holdfasts of *Ecklonia* are found to attach to the blocks after one month of growth. Juveniles developed from meiospores released from the transplanted sporophytes appear in late December and become young plants in early January. In May, new beds of *Ecklonia* are formed around the blocks. A transplanted area of 9 m^3 can be expected to form a new *Ecklonia* bed of about 3000 m^2 area. Although many plants gradually disappear (due to grazing and wave action during summer), surviving plants begin to form spores until the end of August. Thereafter, a new community of *Ecklonia* can be

Fig. 9. Construction of artificial seaweed beds (transplantation of young plants).

expected to become established on the same rocks. Transplantation, by attachment of adult plants on concrete blocks, has proven to be a most effective method of establishing new algal beds in Korea.

4. Transplantation of young plants

Young plants, particularly of *Laminaria* and *Undaria*, can be anchored using concrete blocks or ropes as substrata. The substrata with attached young plants are transplanted on the bottom of rocks or artificial reefs after they are seeded (Fig. 9).

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Current status and problems of isoyake in Japan

Daisuke FUJITA *1

Abstract: In Japan, decrease of seaweed beds has been noticed by fishermen for more than a century and called isoyake. In the modern context, isoyake is defined as decrease or disappearance of upright seaweed beds resulting in the formation and maintenance of poorly vegetated area on the shallow bedrock and stony beds, other than seasonal and slight yearly fluctuations. Seaweeds decrease when they were grazed / browsed by herbivores (e.g., sea urchins and/or herbivorous fish), withered in waters with high water temperature, inhibited for germlings to attach and grow by sedimentation, and/or detached in storms. Some are natural, but the others are highly anthropogenic. The resultant poorly vegetated areas occur most often offshore of seaweed beds, sometimes zoned between shallow and deep beds or patched among the beds. Isoyake has increased during the 20th century; now most of coastal prefectures have more or less isoyake areas. The restoration of seaweed beds has often been unsuccessful because (1)drastic changes in coastal environments, (2) misunderstanding of isoyake, (3) inappropriate selection of restoration method, (4) decrease of young fishermen, (5) limited information on planning and measures, (6) short of social support system, (7) limited commercial usages for priceless herbivores. In 2007, Fisheries Agency published an official guideline for promoting restoration of seaweeds. The principle shown in the guideline is the removal of factor(s) inhibiting formation of seaweed beds; the recommended actions include the adaptive management and collaboration among fishermen, administrative, specialists and citizen. The guideline has been popularized by local meetings and demonstrated in restoration trials lead by supporters, i.e., experienced specialists. Now urchin barrens are highly recoverable to seaweed beds by removing sea urchins, but further technical developments are needed to restore seaweed beds when barren maintains by other factors, e.g., herbivorous fish, high density of snails or sedimentation.

Introduction

Recently, seaweeds have been used much more than before for the construction of 'healthy society' because of multifunctional aspects of the seaweed beds as well as useful constituents of seaweeds such as phycocolloids and tasty amino acids. However, further expectations (e.g., energy source, CO_2 sink) for utilization of the seaweeds and their beds have been much more difficult because seaweed beds have decreased all over the coasts in Japan. The decrease of seaweed beds has been known for more than a century as isoyake or isogare and not only the recent problem (Fujita 2002, 2009). The cause, process, period and extension of the isoyake are different from coast to coast and also changing from age to age (Fujita 2009). In old days, many researchers avoid studying isoyake because of its chaotic nature. Even now, although the number of articles and reports have increased (Kuwahara *et al.*, 2005), extensive and sustainable recovery of seaweed beds have not yet succeeded; aforestation methods by stone piling and deployment of concrete blocks, which intensively change coastal habitats, have been promoted without enough monitoring and discussions (Fujita *et al.*, 2010). In the present paper,

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the author introduced the current status of 'seaweed beds and 'Isoyake' and discussed the problems from various points of views.

What is 'Isoyake'?

As stated above, decrease and disappearance of seaweed beds have been called isoyake or isogare (Yendo 1903), and the resultant barren bottoms, yakeiso or yakene in an old paper (Kishinoue 1894). Once seaweed beds have reduced, production of coastal fisheries have drastically reduced (Yendo 1903) because of suppressed growth ('e.g., meat of abalone, gonad of sea urchins) and reduction of commercial seaweed (e.g, *Gelidium*, *Saccharina*, *Eisenia, Ecklonia, Sargassum*) and related fish and shellfishes (e.g., rockfish, lobster) (Fujita 2002, 2009, Fisheries Agency 2007). Chronology of isoyake in Japan will be discussed elsewhere (Fujita, in prep.).The decrease of fishermen's income is most serious with the additional influence such as decrease of wild resource and damage of seascape resulting in the disappearance of regional attraction, i.e., decrease of sight seekers.

Up to now, the term isoyake has been defined in various ways, including following of old literature, distorted interpretation which neglects the history and mention of the other intertidal phenomenon (Fujita 2002). After reviewing, the author (Fujita 2002) defined as follows; a phenomena of decrease or disappearance of beds of upright seaweed (moba in Japanese) resulting in the formation and maintenance of poorly vegetated area on the shallow bedrock and stony beds, other than seasonal and slight yearly fluctuations. Isoyake includes some urchin barrens but not stable ones often found at offshore of seaweed beds. The definition was adopted in the 'Isoyake Taisaku Guideline' (Fisheries Agency 2007). The definition should not include items such as which factor(s) cause isoyake, how the resultant area look like, how much degree the related commercial resources are influenced, and how long time is needed because they are highly dependent on the topography, oceanography, biota and the history of utilization and development in coastal areas (Fujita 2002, 2009, Fisheries Agency 2007).

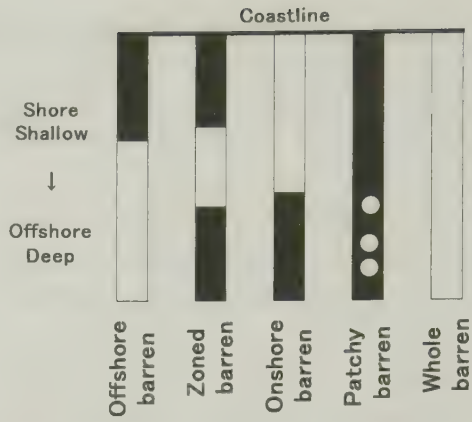

Fig. 1. Location of isoyake in seaweed beds from shore to the lower limit of its bed. (Fujita 2002)

The bottom status of poorly vegetated area after deforestation includes high coverage of crustose coralline algae, denuded rock, survival of tolerant algae or proximal parts of grazed/browsed/withered upright algae, and/or accumulation of soft sediments, all of which remind us barren scenery, something like fired housings and forests as 'yake' in the word isoyake means burnt. Most of isoyake occurs as a zone in the offshore or middle of seaweed beds parallel to the coastline; the latter includes two types, zoned and patchy barrens as shown in Fig. 1 (Fujita 2002, 2009, Fisheries Agency 2007). The most important in the further discussion on isoyake is to pay more attention to the current decrease of seaweed beds, to stop the trend and to start restoration of seaweed beds. However, we now know that each type schemed in Fig. 1 can be also recognized in wild vegetation pattern other than isoyake. For example, the offshore communities in areas deeper than seaweed beds often look like isoyake because of limited light intensity and water motion, accumulation of sediments and/or abundance of herbivores (mainly sea urchins). Therefore the use of the word isoyake should be restricted to mention the 'decrease of the stable seaweed beds' but not to include the stable permanent barrens. Of course, the definition of isoyake is too much comprehensive to treat each local phenomenon and to build working hypothesis there because the biota and environmental conditions are quite different from site to site in Japan elongated from subtropical to cold temperate, comprising of exposed and sheltered, or eutrophic and oligotrophic coasts. It is

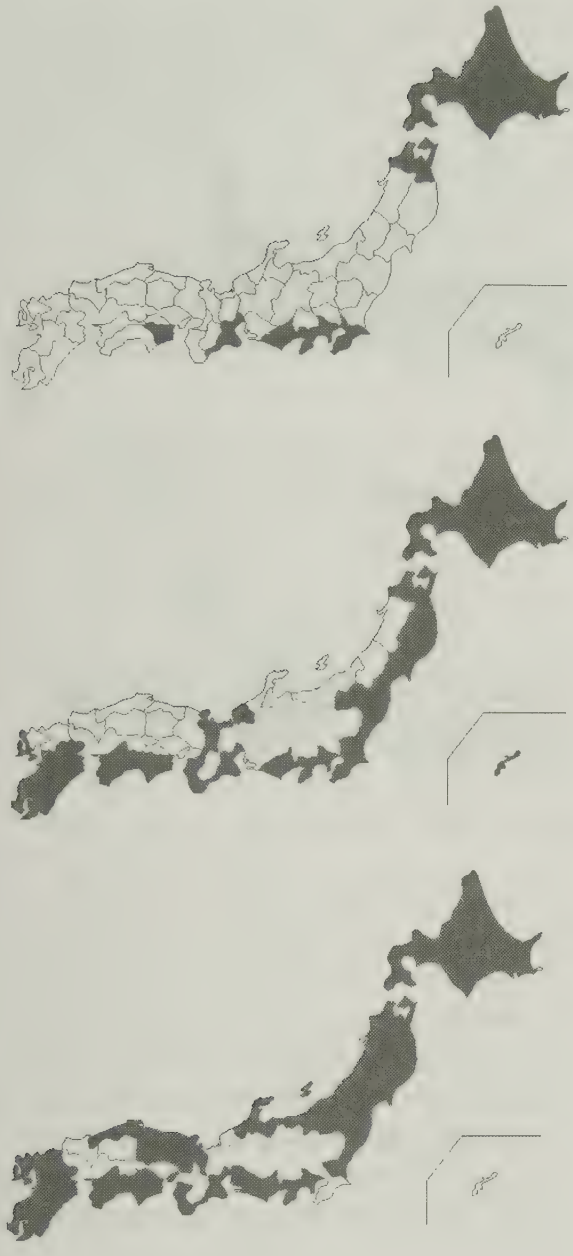

Fig.2. Chronological increase of isoyake at prefectural level in Japan.
Top: early 20th century; middle: late 20th century; bottom; early 21st century.

desirable for each coastal prefecture to positively promote the seaweed restoration projects by delineating the local isoyake phenomena and setting the practical definition to which administrative can treat the project as done in Kochi Prefecture (Kochi Prefecture 2008).

Current status of 'Isoyake' and causative agents in Japan

Fig.2 shows the changes in distribution of isoyake at the prefectural level in Japan. As shown in the figure, number of prefectures with isoyake increased from the beginning of 20th century, through the latter (1980' s) of the century, to the beginning (2005) of the 21st century; most prefectures suffered from the phenomena. Figs. 2 (bottom) and 3 to 5 are based on the data of hearing to all coastal prefectures by Fisheries Agency in 2005. Although presence of isoyake was not reported from some prefectures (not pasted in Fig. 2 (bottom)), more or less seaweed beds have actually decreased even in these prefectures. Akimoto *et al.*, (2009) confirmed the presence of 83,798 ha (41.6%) of 201,212 ha reported in 1994 (data obtained in 1989 to 1991 were used), among which 18,538 ha (22.1%) was lost until 2006-2008.

The major decreasing bed-forming seaweeds are cold temperate kelp *Saccharina* in Hokkaido and Northeast coast of Honshu, warm temperate kelps such as *Ecklonia* and *Eisenia* and *Sargassum* in Honshu, and *Gelidium* in some local areas in Honshu and Shikoku Islands (Fig. 3).

The reasons thought to cause and/or maintain isoyake are, though some of them are not popular, 1) changes in oceanographic conditions, 2) deficiency of nutrients, 3) outflow of freshwater, 4) changes in climatic conditions, 5) grazing or browsing by herbivores, 6) Competition for space with attached organisms, 7) sedimentation, and 8) public nuisances including industrial wastes (Table 1). The extension and duration of isoyake are highly variable in these phenomena and the causative agents listed above often damage seaweed beds in combination. Seaweeds decrease when thalli are 1) grazed or browsed by herbivores (Grazing-type), 2) when thalli are withered (Withering-type), 3) when reproductive cells (including dispersal propagules and germlings) cannot attach to the substrata or germinate (settlement inhibition-type) and/or 4) when thalli are dislodged in storms (dislodgement-type). (Fujita 2002, 2009; Fisheries Agency 2007). All of these processes are common in healthy seaweed beds; the beds decrease when they exceed each usual range by the reasons listed above.

Fig. 3. Distribution of major decreasing bed-forming seaweeds in Japan.

The most important among the four types is the grazing/browsing type (Fisheries Agency 2007). The herbivores which intensively and extensively affect the distribution of seaweed beds are sea urchins (Fujita *et al.*, 2008) and herbivorous fish (Fujita *et al.*, 2006). Local reduction of seaweed beds are often brought by the grazing by gastropods such as horned turban *Turbo cornutus*, small snails (e.g., *Chlorostoma*), and sea hares *Aplysia kurodai* and *A. Juliana*. Among the herbivores, grazing by sea urchins has been paid attention as structuring force in the world (Lawrence 1975, Harrold & Pearese 1987): the domestic dominant causative species are *Strongylocnetrotus nudus* in northern Japan and *Anthocidaris crassispina* and *Diadema setosum* in southern Japan (Fig. 4). The strongylocentrotids and diadematids are dominant in cold/warm temperate waters in northern hemisphere and tropical to subtropical waters, respectively (Lessois *et al.*, 2001, Biernmann *et al.*, 2003), both of which affect the seaweed vegetation and its distribution (Lawrence 1975, Fujita *et al.*, 2008).

On the other hand, notable herbivorous fish are tropical/subtropical species such as *Siganus fuscescens, Calotomus japonicus, Kyphosus bigibbus* and *Prionurus scalprum*, which damage seaweed beds in southern to central coasts of Japan (Fig. 5). Among them, *S. fuscescens* is recorded from all over the domestic warm temperate coasts (up to 41° N, i.e., except Hokkaido, but quite rare in northeastern coasts of Honshu) and its browsing on seaweeds are detected in the highest latitude (at least 38 °N) among the four species (Fujita *et al.*, 2006).

Some people, even researchers consider that recent elevation of water temperatures (global warming?) induced the tropical/subtropical herbivores such as *Diadema* and herbivorous fish to the warm temperate areas of Japan. However, this is not true because both of them have been known for more than a century. For example, *Diadema* was reported by the first Japanese echinoderm taxonomist Shigeyasu Yoshiwara (Yoshiwara 1898) in Boso, Miura and Izu Peninsulas at the end of 19th century and *Siganus fuscescens* was reported from northern Kyushu as early as 1708.

In the hearing in 2005, coastal prefectures also

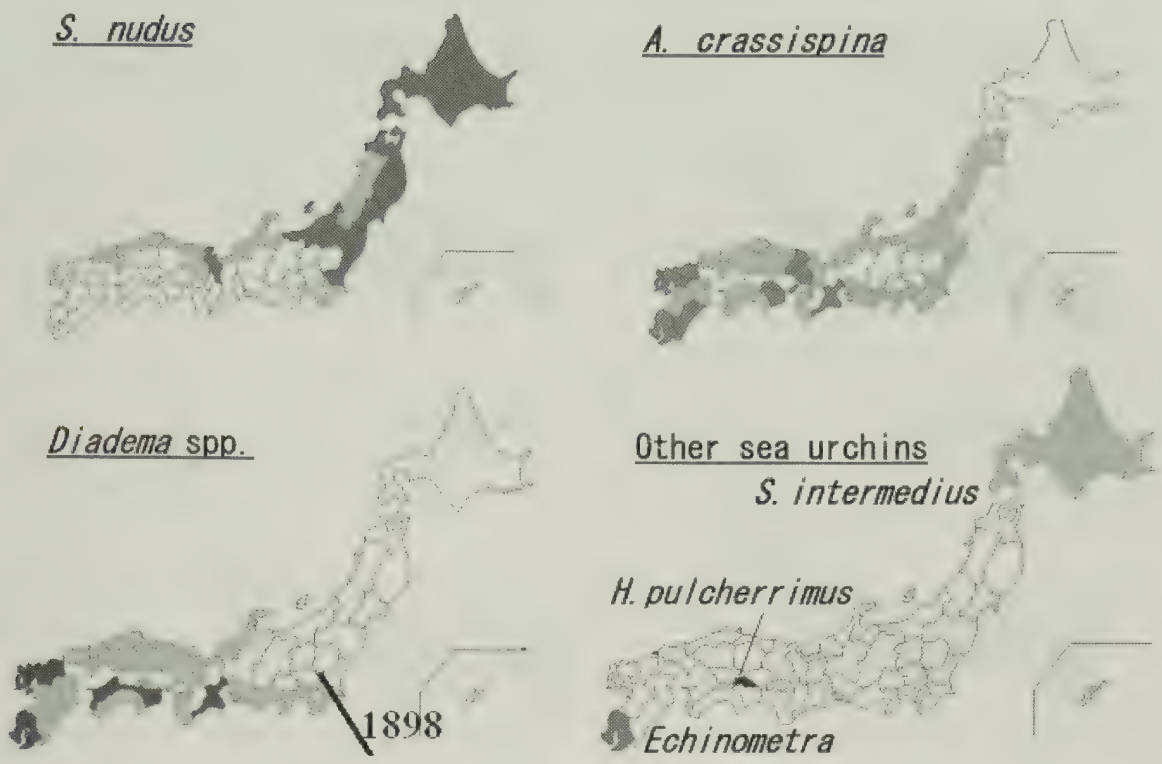

Fig.4. Distribution of major species of sea urchin causing deforestation of seaweed beds in Japan. Prefectures with thin and dark color show the occurrence of each species and the presence of intensively grazed areas, respectively, except the map of other sea urchins. Note that tropical/subtropical species *Diadema setosum* has been known since 1898 from Boso Peninsula, central Pacific Coast of Japan.

enumerated factors other than grazing/browsing by sea urchins (see Fujita *et al.*, 2008) and herbivorous fish (see Fujita *et al.*, 2006), namely, stagnation/turbidity of waters accompanied with sedimentation, oceanographic fluctuations/elevation of water temperatures, typhoon, grazing by gastropods, deployment of coastal structures (breakwater, long piers, artificial reefs etc.), warm waste discharged from power plants, and excretes from fish aquaculture cages (see Fujita *et al.*, 2010). However, the discussions on effects of coastal structures, power plants and aquacultures are often neglected or tabooed by coastal prefectures, resulting in insufficient answers in the hearing. Therefore the nation-wide survey is needed to detect any effects of the coastal structures and activities on the seaweed beds. These are sometimes unavoidable for protection of coastlines as well as the development of local economy, but their effects are much more intensive and extensive than expected; further cautions are needed for the renewal plan. We have to note that plural causative agents co-affect on seaweed beds and causative agents are often different from maintenance factor in isoyake. Generally, in Japan, water pollution by mine and industrial wastes were much more serious until 1970's than now. The pollution has been removed because of movement of the factories from domestic to abroad and replaced by river improvements and shore protection, which were promoted publicly to recover the sluggish economy and to create hiring labors as well as to keep residential ease, safe and richness. The fishermen have lowered their interests and capabilities in seaweed bed managements because of changes in fisheries (i.e., catch of wild rocky resource to aquaculture), resulting in the less maintenance of seaweed beds (i.e., removing herbivores and competitive algae). Recent elevation of water temperatures and behavioral changes of coastal currents as well as increasing abnormal climatic events, accompanied with global warming, can also be a threat although little reliable studies (only as

Fig.5. Distribution of major species of herbivorous fish causing deforestation of seaweed beds in Japan. Prefectures with thin and dark color show the occurrence of each species and the presence of intensively browsed areas, respectively. The prefectures with thinnest color in the map of *S. fuscescens* show the episodic record as a rare case of occurrence of the species. Note that *S. fuscescens* was reported as early as 18 century from northern Kyushu.

physiological experiments in simplified conditions or *in situ* monitoring, but not including tests to reject other factors, such as structural changes in coastline and stock levels of predators (as controller of herbivores) and herbivores (Fujita *et al.*, 2010). Now, even in areas in which climatic and oceanographic changes had been mentioned for the decrease of seaweeds in older days, anthropogenic factors are becoming more serious than before, which can affect directly on the physiology of seaweeds and indirectly on the activity of herbivorous sea urchins and fish (Table 1). The question mark on global warming (elevation of water temperatures) in Table 1 is not because of doubting its effects to seaweed beds but to keep in mind the necessity of discussion whether it is the true or major causative agent. The feeding activity of herbivores is not only dependent on water temperatures but food condition (i.e., seaweed vegetation), water motion and anthropogenic factors. For example, intensive grazing on seaweed by sea urchins can be caused by a variety of reasons, including baby boom, release of juveniles and transplantation from deep to shallow waters, decrease of drifting seaweeds (cease of seaweed culture, overexploitation, yearly bad growth etc.), decrease of sea urchin fishery, decrease of predators on sea urchins (crabs, rockfish etc.), increase of habitats (piled stones, deployed concrete blocks, etc.) and stagnation of waters as well as elevation of water temperatures (Fujita *et al.*, 2008).

Publish of a guideline and the subsequent activities

Although the studies and projects on isoyake have been increased (Nakatsu 2005, Kuwahara *et al.*, 2006), success in recovery of seaweed beds are quite limited because of the reasons as follows; (1)drastic changes in coastal environments,.(2) misunderstanding of isoyake, (3) inappropriate selection of method, (4) decrease of young fishermen,

Table 1. Causing or maintenance factors (including tentative) of isoyake in Japan

Factor	Example	Note
1..Oceanographic changes	Dominance or shoring of Kuroshiwo and Tsushima Current, Ashoring of the first branch of Oyashiwo, Shoring of floating ice.	Elevation of water temperature in winter or summer (accompanied with short of nutrients). Floating ice also plays role in clearance of weed on rocks.
2. Short of nutrients	Prohibition of dumping squid viscera, increase of land-slide barrier, decrease of river flow and disturbed dispersal	Short of N and P (and Fe?) can reduce the growth and/or maturation of seaweeds. Alteration in coasts and watershed as well as loss of feedback of nutrients into coastal community can enlarge the geographical unbalance of eutrophic and oligotrophic areas.
3.Inflow of fresh waters	Deforestation in land forests (causing flood, periodical discharge of freshwaters, cultivation in open fields, heavy or prolonged rain,	Reduction of salinity has been thought to cause decrease of seaweeds; turbidity and/or accumulation of organic silts are more serious in modern context.
4.Climatic factors	Typhoon, warm winter	Extensive deforestation was known only when Kitty Typhoon (1949) attacked west coast of Sagami Bay.
5.Grazing or browsing by herbivores	Sea urchins (*S. nudus*, *D. setosum*, *A. crassispina*), gastropods such as *T. cornutus*, aplysian sea hare, herbivorous fishes (*S. fusges cens*, *C. japonicus*, *P. scalous* and *K. bigibbus.*)	Sea urchins and herbivorous fish are most important; *T. cornutus* and *Aplysia* often overgraze *Gelidium* and *Undaria* beds, respectively.
6.Occupation of hard substrata	Crustose coralline algae, polycheates	Crustose coralline algae (CCA) can live even poor-vegetated area (including deforested area) because of its high tolerance to grazing, wave, turbidity and accumulation of silts. The dominance of CCA is a result of Isoyake rather than the cause of the phenomenon.
7. Burial of hard substrata	Volcanic ash. drift sand. silt & floc	Damage by volcanic ash was reported around Mt. Komagatate, Mt. Fugen- dake and Miyake Island. Drift sand and silt & floc are highly linked with alteration of coasts and watersheds.
8.Public nuisance	Mine or industrial wastes, sewage, warm waste from power plant, river improvement, enlarging ports, breakwater coastal road, cultivation on upstream land, agricultural chemicals.	After closing domestic mines and improving water quality comparative to economical high growth period, increase of coastal structures facilitate stagnation of waters and accumulation of silt & floc.
9. Fisheries and aquaculture	Hard use as fishery ground, overharvest of seaweeds, deployment of concrete blocks, release and transplantation of herbivores such as sea urchins, excretes and unfed pellets in fish culture, stagnation caused by crowded culture cages or rafts	Some barrens have experienced the overharvest of commercial products including abalone, agar weeds and kelp. Unsuccessful improvements of fishery ground and transplantation of sea urchins from deep barren to shallow algal refuge has enlarged deforested areas.
10. Others	Hot spring, decrease of seepage caused by pumping underground water, virus or bacterial disease etc.	Some has not been scientifically elucidated, others are superstitions.

(5) limited information for planning and practice for the restoration, (6) short of social support system for promoting restoration, (7) limited commercial usages for priceless herbivores such as less gonad sea urchins and tasteless herbivorous fish. Details were discussed elsewhere (Fujita 2009).

At the end of fiscal year 2006, Fisheries Agency (Japan) officially published 'Isoyake Taisaku Guideline' (Taisaklu=measures) to practically restore seaweed beds from isoyake areas as a result

of 'Emergent Model Project for Recovering from Isoyake' (2004-2006). The principal in seaweed bed restoration should be the removal or reduction of major factor(s) which inhibit the formation (or recovery) of seaweed beds, in most cases, grazing browsing pressure. Therefore the guideline emphasized the need to remove herbivores from bottoms desirably as fisheries because this is the only breakthrough which fishermen themselves can be a core of the restoration program as professionals. Collaboration among administrative boards, researchers and citizens (both local resident and municipals) as well as adaptive management are strongly recommended in the guideline. In the program, introduction of simple experiments to identify the inhibiting factor(s), monitoring of current status of seaweed beds and recording the results of any action for restoration are important to feedback and bring successful results. Furthermore, in order to induce secondary damage to seaweed beds, soft restoration techniques are preferable to hard techniques (i.e., piling of stones, deployment of concrete blocks). This is because artificial beds often provide habitats for sea urchins and herbivorous fish. Among the collaboration, introduction of citizen can be a key not only to provide an amount of labors in the depopulated or aged fishing village, but to activate the village by promoting practical human exchanges between cities and fishing villages. They will also be a power to inhibit undesirable destructive plans in coastal managements (e.g., land reclamation, overprotection) which should be dissolved as habitat problems and to avoid secret negotiation between local office and fishermen's cooperatives.

After publishing the guideline, Fisheries Agency started a subsequent project, 'Large-scale Project for Promotion of Recovery from Isoyake' (2007-2009). In the project, guidance was held in requested areas (more than 10 sites a year) and a training course (monitoring of seaweed beds, once a year) were opened to researchers in local fisheries institutes and teachers in fishery high schools. Furthermore, practical restoration programs were developed with the help of supporters (specialists of full experiences in restoration) at 10 sites. Unsolved problems including the defense from browsing by herbivorous fish are also continued to study in the project. Now, in most 'urchin barren', at which grazing by sea urchin (no escape, no hide out) solely contributes the maintenance of isoyake, continuous removal of sea urchins promises the restoration of seaweed beds. The effective and efficient system for the maintenance and enlargement of the beds should be established as the next step. On the contrary, seaweed beds are hardly recovered when browsing by herbivorous fish (professionally eat and escape) is dominant, when waters are stagnated and/or sedimentation of silts and turbidity are dominant, and when 'urchin barren' is accompanied with other herbivores (fish, snails, sea hares) or sedimentation.

Perspective and remained problems

The 'Isoyake Taisaku Guideline' (Fisheries Agency 2007) is a crystal of the knowledge of the participant prefectures and committee comprised of specialists, explaining principal concepts and 25 systematized component techniques. Following the landmark guideline, some prefectures published local version of the guideline (e.g., Kochi Prefecture 2008) and planned and practiced in ways more specified to the local environment and biota. As stated above, urchin barren, particularly when maintained solely by sea urchin, has been demonstrated to turn to seaweed beds by removal of sea urchins in many coasts of the country from Kyushu to Hokkaido (Fujita *et al.*, 2008). On the contrary, when isoyake is maintained by plural herbivores (particularly escapable fish, high density of snails etc.), restoration of seaweed beds is quite difficult. Furthermore, where the coastlines and rivers are drastically changed irreversibly by civil engineering such as land reclamation and dam construction, restoration efforts scarcely result in the recovery of original states before isoyake. Recently, natural disaster type of isoyake is decreasing, while anthropogenic and complex types are increasing; the author call these types 'structural barren', which is similar to the structural depression in economics (Fujita 2009).

As the local fishing villages are suffered from sluggish economy, depopulation, aging of fishermen and increase of part-time fishery as a combined

provocation, now is the timing to reestablish new systems and rules to manage seaweed beds as well as coasts and resources living there. Under the present circumstances, the most important is not to continue 'barren' discussions on the desk, but to start any actions including trial and error (to be directed in adaptive management) for the dissolution of isoyake problems. In addition, oceanographic literacy (PADI 2000, Tokyo University of Marine Science and Technology 2010) should be strengthened in education of national people. More practically, development and popularization of knowledge and technology for monitoring and managing seaweed beds will be the base on the activity (Fig. 5). The final target should be the establishment of moderate fishery and balanced utilization of coasts and resources. As stated in the introduction, seaweed beds are important communities in various aspects; the values of component seaweeds are elevating day by day because of promised contribution to the human health. Therefore, many people should take part in the monitoring and maintenance of seaweed beds. For example, local residents, amateur divers and anglers can be volunteers, seaweed industries and electric and construction companies can participate in these activities through CSR (Corporate Social Responsibility) projects. All of them can support fishermen to monitor and restore the seaweed beds. Marine high schools and universities of fisheries, although both of them are losing field works and departing from fisheries, should rear key persons who can be core of the activities. Fates (e.g. coastal changes) and restoration of seaweed beds should not be discussed secretly between the local offices and fisheries cooperation but should be open to local society to find the best ways by introducing a variety of knowledge and techniques.

Acknowledgments

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Resources of *Laminaria* (*Saccharina*) *japonica* on the southwestern coast of Sakhalin island in recent years. Tasks of investigations for the near period

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Abstract: The current state of the resources *Laminaria japonica* on the coasts Sakhalin island is satisfactory. In also the time, the large areas of stone ground are not populated. Recent year the resources of algae continue to be reduced, especially in the places of fishing. Exception case with associations of macrophyte was found in the extreme south of Sakhalin Island (fishing is not). Here the decrease of the biomass of algae is not observed. To the next five years we planned the complex investigations of hydrobiological for the purpose to establish the reasons for the reduction of the resources of *Laminaria japonica* on the coast of Sakhalin. Analogous investigations are planned by Japanese researchers from Hokkaido Central Fisheries Experiment Station on the west coast of Hokkaido. As the hypothesis three groups of the reasons, which most probably influence the development of the succession of associations, are examined by us. These are oceanographic causes, anthropogenic and biotic factors. The force of the influence of each for us is in prospect to determine in the course of the planned five-year studies. For the solution of the problems presented, Sakhalin Research Institute of Fisheries and Oceanography plans to create two testing areas for the hydrobiological monitoring, with the setting for each of the station of the autonomous measurement of temperature. Annually planned to make oceanographic observations in Sea of Japan along 47° 20' N. Furthermore, in the work will be begun to operate one autonomous stream gauge (shore of the southern part of Tatarskiy Strait, Japan sea).

Introduction

Laminaria japonica is a single species of brown algae that is commercially taken along the south and southwestern coast of Sakhalin Island (Fig. 1). As regards to commercial capture of *Laminaria japonica*, we divide the entire southwestern Sakhalin coast and Aniva Bay into two regions of fisheries: traditional and potential region. In traditional areas, *Laminaria japonica* has been continuously taken since the 1950s of the last century, and in the potential region this species has been taken sporadically. Not more than 10 enterprises are successfully working in the traditional region where native people are involved as seasonal workers. *Laminaria japonica* is captured at shallow sites down to 4 m in depth using an algal gear; a catch per effort (1 person for a working day) is 500 kg. At deeper than 4-5 m, algae are taken with the help of divers; a catch per effort (1 diver for a working day) is 1500 kg. No damage is caused to thickets of *Laminaria japonica* by these two methods. When thalli with rhizoids are captured, substrate is released for new spores, and mosaic capture of plants keeps enough thalli for their reproduction.

The recent researches during 10 years have shown a steady low stock of *Laminaria japonica* in the traditional region and comparatively high stock in the potential region (Fig. 2).

However, along the southwestern coast of Krilion Peninsula (southwestern coast of Sakhalin Island) a total *Laminaria* biomass has gradually decreased

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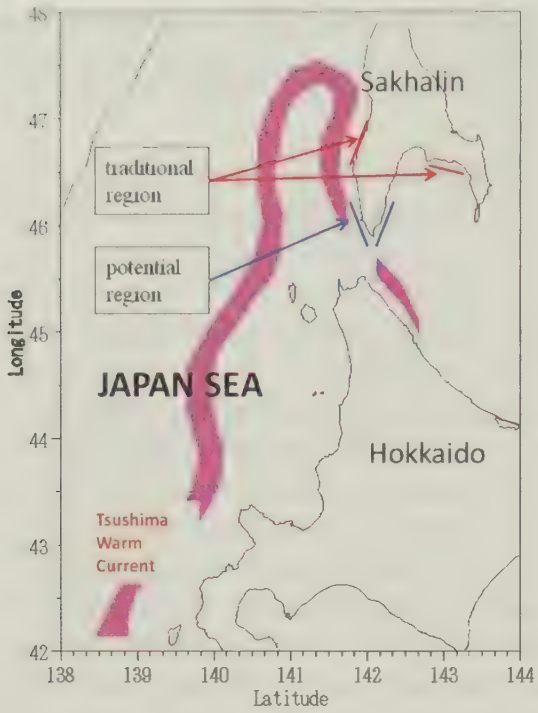

Fig. 1. The region of *Laminaria japonica* fisheries on Sakhalin

as well, and for the last three years it declined as great as three times. In our opinion, there has been a change in dominants since 2005 in this commercial region. In plant communities, *Laminaria japonica* became an attendant species instead of the co-dominant one, and its number continues to decrease. It was replaced by *Kjellmaniella* and *Arthrothamnus* (See Table 1).

Despite reducing in *Laminaria* distribution areas, the algal size-weight characteristics actually did not change after the 1950s. Only during the last 10 years there have been observed significant fluctuations in these characteristics.

The diving counting survey in 2007 showed that in the traditional region *Laminaria japonica* formed monodominant thickets at depths from 0 to 3 m. The width of thickets varied from 6 to 150 m. In 2007, a projective bottom algal cover varied from 20 to 100%. The area occupied by commercial algae was 0.6 km^2. The survey showed that density of commercial thalli varied from 2 to 28 ind./m^2 (average; 9.9 ind./m^2) specific biomass from 0.38 to 32.8 kg/m^2 (average: 10 kg/m^2). The area occupied by the non-commercial algae was 0.07 km^2; their mean density was 163 ind./m^2, mean specific biomass 8.4 kg/m^2. Mainly commercial thalli prevailed (85%) in the *Laminaria japonica* thickets. Based on the 2007 survey, this year can be considered as productive. As a result, in 2007, a commercial stock of *Laminaria japonica* along the western Sakhalin coast was minimal for the last 10 years.

Thus, in 2007, as in previous years, resources of *Laminaria japonica* remained at the extremely low level. On the contrary, its commercial capture (in traditional region) increased comparing to 2005.

We may conclude that the problem of *Laminaria japonica* resources is actual, so it is important to find solution for this problem.

In this connection, SakhNIRO and Hokkaido Central Fisheries Experiment Station scientists are ready to begin joint researches and to implement their part of works.

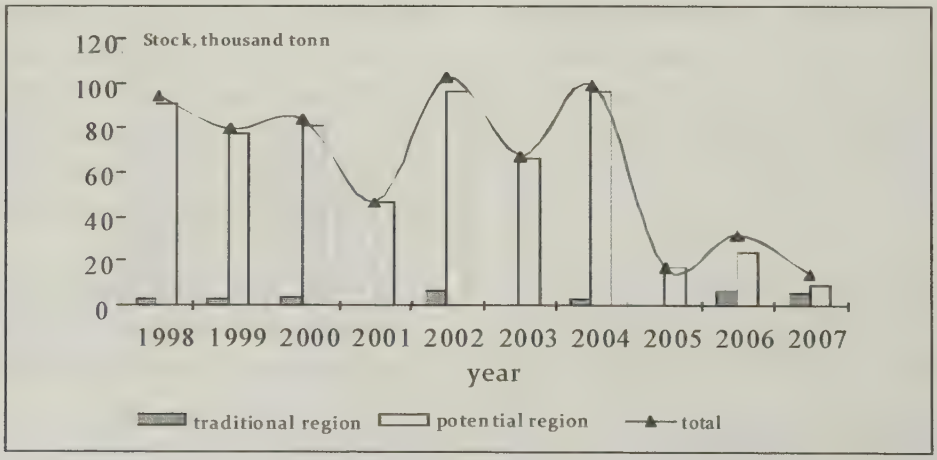

Fig. 2. The moving of stock *Laminaria japonica* of the southwest Sakhalin

Goal and tasks of Program

Based on the goal of Program: to reveal causes of reducing the *Laminaria japonica* fields along the southwestern Sakhalin coast and to develop methods for their recovery, the following tasks are to be performed.

1. To find trends of seasonal and interannual changes in quantitative characteristics and distribution areas of *Laminaria japonica* and Corallinales associations on the study sites near stm. Antonovo and Cape Tukotan;
2. To perform a seasonal re-description of macrophytobenthos composition on the study site near stm. Antonovo. To make a comparative analysis of the results obtained with the archive materials;
3. To study dynamics of *Laminaria japonica* sporification in order to determine optimal timing for seeding spores on natural and artificial substrates when recovering its fields.
4. To study daily diets of sea urchins inhabiting *Laminaria* fields in order to calculate necessary areal values when recovering.
5. To obtain data on currents and water temperature in the southwestern Sakhalin coast during the period of development of *Laminaria japonica* microscopical stages. To make analysis of chlorophyll-a concentration, contents of biogenic elements, water temperature and salinity, and *Laminaria* survival in the long-term aspect (September – March).
6. To conduct experimental works on seeding coralline-covered bottom with zoospores of *Laminaria japonica.*

Methods for implementing research works

Different methods are intended to be used during research works:

1. A diving method for sampling will be used to perform all six tasks of study. However, it will be particular depending on specific task.
2. The work with archive materials will allow making a comparative analysis of the results obtained with the data of past years. Besides the own archive data, it is planned to get acquainted with the experience of Japanese researchers studying the phenomenon "isoyake".
3. Measuring devices for temperature, salinity and dissolved oxygen are suggested to be used on the study areas from a boat once a month. They are to record intra-daily changes of water temperature during development of zoospores and gametophytes and other process (since September through April). Besides, one stationary current gauge will be used. The research vessel "Dmitry Peskov" and TeraScan satellite system will be

Table 1. Change dominant in community beside Krilion Peninsula

Year	Seaweed	Sown area km^2	Biomass, kg/m^2	Total biomass, t.t	Commercial biomass, t.t
1998	*Laminaria japonica*	0.01	20	0.3	0.2
	Arthrothamnus kurilensis	0.014	7	0.1	
	Kjellmaniella crassifolia	0.013	5	0.07	
2007	*Laminaria japonica*	0.01	2	0.03	0.02
	Arthrothamnus kurilensis	0.017	9	0.15	
	Kjellmaniella crassifolia	0.019	7	0.13	

used to conduct Hydrographic surveys.

4. After sampling by means of the diving method, it is necessary to preserve and then to make camera processing of materials.

Work areas and Schedule time

The Program was intended for 5 years. The work area SakhNIRO is located between the town of Chekhov and Shebuninka River (Fig. 3). The more detail surveys will be conducted in the coastal zone between Cape Tukotan and town of Nevelsk, and also on study areas near stm. Antonovo and Cape Bogdanovich. Stationary instruments of the type "Potok" will be set on each study area for measuring near-bottom water temperature. They are to record intra-daily changes of water temperature during development of zoospores and gametophytes (since September through April). A stationary current gauge will be set between Moneron Island and Krilion Peninsula for the period since September through April. Oceanographic observations will be conducted along the latitude linking Cape Slepikovskiy and Cape Zolotoy. The work interval will be twice a year (April and September). The 5 year researches are expected to be resulted in revealing causes of stock decline for *Laminaria japonica* and developing methods for recovering its resources.

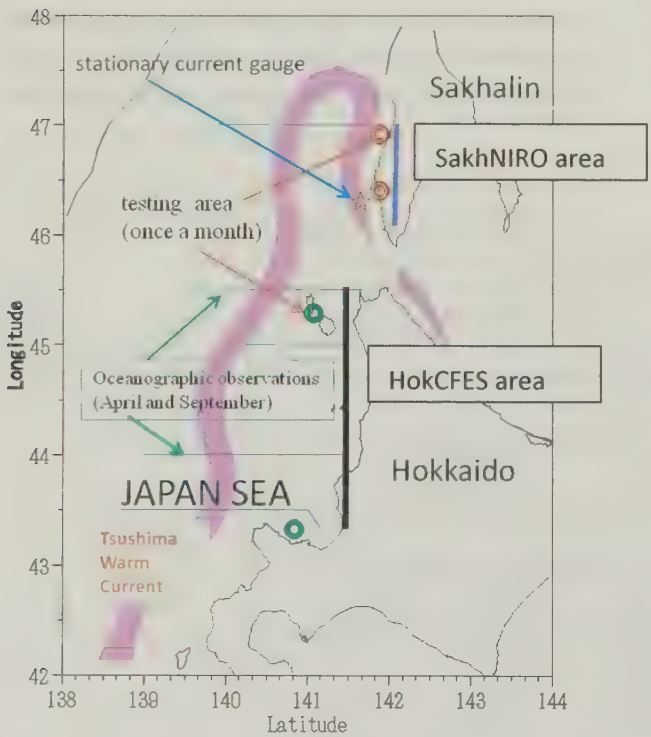

Fig. 3. Work areas and Schedule time

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Comparisons between East-Asian isoyake and deforestation in global kelp systems

Michael H. Graham [*1]

Abstract: Seaweed deforestation (isoyake) is a conspicuous phenomenon in many temperature/polar regions of the world and often results in strong ecological and economic impacts to local human communities. The study of isoyake in East Asia (especially in Japan) has a long history, however the resulting literature is generally inaccessible to researchers that do not speak Asian languages. This study integrates knowledge of the causes and consequences of isoyake in East Asia into an emerging global model of the causes of deforestation in non-Asian kelp systems. Isoyake in southern regions of East Asia result from a concurrence of increased herbivory by fish and sea urchins of sub-tropical origin with periods of decreased seaweed production due to poor oceanographic conditions. Such processes are similar to those that cause deforestation in other warm-temperate kelp systems (*e.g.* southern California and northern New Zealand) and may be enhanced during periods of ocean warming. Alternatively, isoyake in northern regions of East Asia result primarily from uncontrolled sea urchin grazing; inherently low kelp productivity in these regions cannot balance the high rates of kelp consumption. As such, these regions appear similar to other high latitude/low productivity kelp systems in which large enduring sea urchin barrens often exist in the absence of external controls on sea urchin abundance (*e.g.* predation or harvesting by humans). Therefore, the diversity of causes of isoyake in East Asian systems appears to encompass the full range of deforestation processes described for high- to low-latitude kelp systems worldwide. The unique situation in which high seaweed and herbivore diversity coincide with high variability in oceanographic processes appears may make East Asian seaweed systems more vulnerable to perturbation than other temperate kelp systems.

Introduction

Seaweed forests are well recognized to provide essential habitat and energy to nearshore areas worldwide (Mann 1973, Dayton 1985, Barnes and Hughes 1988, Duggins *et al.*, 1989, Schiel & Foster 2006, Graham *et al.*, 2008), with subsequent enhancement of local biodiversity, productivity, and human economies (Steneck *et al.*, 2002, Graham *et al.*, 2007, Kang *et al.*, 2008). This is particularly true for systems founded by kelps, large brown algae in the order Laminariales, which have some of the highest productivities known amongst marine autotrophs (Mann 1973, Jackson 1977, North 1994, Graham *et al.*, 2007). When kelps disappear, either naturally or due to human activities, the ecological and economic consequences can be severe (Steneck *et al.*, 2002, Graham 2004). As such, there is growing interest in understanding general processes driving kelp deforestation at a global scale.

Conspicuous seaweed deforestation was first described in Japan in the 1800s and named *isoyake* (Fujita, this issue). Over the last 100+ years an extensive literature has developed in Japanese, and later Korean and Chinese, scientific journals fueled by public and private interests in ecology and resource use of coastal seaweed forests. Most of this literature is in Asian languages and has

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been generally inaccessible to English-speaking researchers since the first description of kelp deforestation in non-Asian systems (reviewed in Lawrence 1975). As such, isoyake research in East Asia has had little impact on the understanding of the causes of kelp deforestation worldwide. The goal of this paper is to discuss the ecology of East Asian isoyake in light on a new model explaining variability in kelp deforestation at a global scale (Graham *et al.* in prep.).

Dynamics of East-Asia kelp systems

Seaweeds are important taxa throughout East Asia, however, kelps are only important in the warm- and cold-temperate regions of Japan, South Korea, China and Russia (Lüning 1990). Isoyake has been described from each of these regions, although the ecology of isoyake clearly differs between warm- and cold-temperate systems, and it is useful to treat these separately.

In warm-temperate East Asian kelp systems, isoyake can be observed in southern Japan (Honshu, Shikoku, Kyushu; Fujita, this issue), South Korea (Kang, this issue), and China (Duan and Ming, this issue). Kelp productivity is moderate in these regions relative to other kelp systems worldwide (Graham *et al.* in prep.), with the dominant taxa being *Eisenia bicyclis* and *E. arborea, Ecklonia cava,* and *Undaria pinnatifida* (Lüning 1990). These kelps appear to have adapted to high seasonal variability in oceanographic conditions driven by fluctuations in the strength and direction of the Kuroshio and Japan currents. As such, these systems naturally degrade during late summer and autumn due to regional ocean warming (Yokohama *et al.*, 1987, Haroun *et al.*, 1989). In recent decades, continued ocean warming has resulted in greater stress to the kelps (Serisawa *et al.*, 2004). Further, sub-tropical sea urchins (Terawaki *et al.*, 2001, Steneck *et al.*, 2002, Tamaki *et al.*, 2005) and herbivorous fish (Masuda *et al.*, 2000, Yamauchi *et al.*, 2006) have become common in southern waters of East Asia during warm seasons, devastating local kelp forests. Although predation in Asian kelp systems is poorly studied, there currently are no known conspicuous predators on sea urchins and herbivorous fish in the region. Isoyake caused by herbivory occurs on both natural and artificial reefs, and appears to be most common in regions of low water motion.

In cold-temperate East Asia, isoyake can be observed primarily in Japan on the west coast of Hokkaido (Fujita, this issue) and in limited areas on the west coast of Sakhlin Island, Russia (Galanin, this issue). Isoyake is not described for the east coast of Hokkaido. In these regions, the dominant kelps are *Saccharina japonica* and *Undaria pinnatifida.* The west coast of Hokkaido has very low productivity relative to other kelp systems worldwide (Graham *et al.*, in prep.) and isoyake here is caused almost entirely by overgrazing by the sea urchin, *Strongylocentrotus nudus* (Fujita, this issue). The only known control on sea urchin overgrazing in this region is high water motion in shallow water, and harvesting by humans; sea urchin harvesting, however, is only possible outside of isoyake where sea urchin gonads are of marketable quality. In Russia, the observation of isoyake is recent and coincides with declines in kelp farming productivity (Galanin, this issue), potentially due to poor oceanographic conditions.

Inclusion into a global deforestation model

Japanese researchers have long understood that isoyake results either when oceanographic conditions degrade kelp production entirely or when kelp consumption exceeds kelp production. In addition to creating artificial habitats to compensate for isoyake, researchers have considered ways to either enhance kelp production or hamper kelp consumption. This approach is entirely consistent with new ideas that have emerged from the study of kelp production and consumption in non-Asian kelp systems. Using ecological and oceanographic data, Graham *et al.* (in prep.) found that kelp production potential varies 30-fold between the lowest (Arctic) and highest (west South Africa) productivity regions, driven by global variability in irradiance, ocean temperature, and nitrate concentrations. Furthermore, kelp production potential decreased predictably with increasing latitude and broad-scale enduring sea urchin barrens were restricted to high latitude systems. The conclusion from this study

was that high-latitude low-productivity kelp systems were more likely to experience imbalance between kelp production-consumption than low-latitude high-productivity systems. Kelp production potential from southern and northern Japan were well predicted by the global model (Graham *et al.*, in prep.).

An additional conclusion of the global kelp model was that low-latitude systems often have a greater diversity of factors that control herbivory populations. Seaweed diversity in warm-temperate regions is generally higher than high-latitude counterparts, and herbivore and predator populations are also generally more diverse due to proximity to the subtropics. In Japan, the southern islands have a high diversity of kelp grazers including various sea urchins, fishes, and snails, coincident with regionally high diversity of kelps of the genera *Ecklonia, Eckloniopsis, Eisenia, Undaria,* and *Saccharina*; these kelp taxa are complimented by many species of *Laminaria, Agarum* and *Alaria* in the north. Sea urchin diseases are also relatively warm water phenomena (Behrens and Lafferty 2004) and sea urchin fisheries are often well established in lower latitudes. As such, the balance between kelp production-consumption can often be shifted in favor of kelp by a greater diversity of sea urchin controlling factors in low-latitude systems. Again, this perspective well explains many key differences in isoyake between the northern and southern regions of East Asia (Graham *et al.* in prep.), where numerous factors appear to cause and control isoyake in the south, whereas sea urchin harvesting appears to be the only controlling mechanism in the north.

Conclusions

Despite numerous endemic kelp taxa and high seasonal fluctuations in oceanography, it is clear that East-Asian kelp systems function similarly to other temperate kelp systems worldwide. Shifts in the balance between kelp production and consumption result in kelp deforestation at a variety of temporal and spatial scales. Although grazers can be important components of isoyake throughout East-Asia, deteriorating oceanographic conditions appear to be a primary cause of isoyake in warm temperate regions, with grazers inhibiting the return of kelp to natural abundances. Sea urchins have a much more direct role in the cause of isoyake in northern cold temperate regions, with ocean warming playing a secondary role. However, it is still unknown whether isoyake are relatively naturally states in East-Asian kelp systems, since the only modern control on sea urchin populations appears to be human harvesting, extreme water motion, or high levels of kelp productivity. The absence of important sea urchin predators, besides the sea otter, which has long been extinct from Japan, is conspicuous.

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Introduction of Isoyake Recovery Guideline (Fisheries Agency, Japan)

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Abstract : Reduction of seaweed beds called 'isoyake' has become a serious problem in most of coastal prefectures in Japan. To restore seaweed beds, Fisheries Agency carried out a national project in cooperation with 16 prefectures and 19 specialists from fiscal 2004 to 2006. Isoyake Recovery Guideline was published in February 2007. Main users are fishermen who should be at the core of the restoration. Main theme is the control of intensive grazing by sea urchins and herbivorous fishes. Major topics are as follows.: (i) adaptive management to lead to successful reforestation through adaptive learning and feedback, (ii) flow chart for selecting techniques through 6 simplified categories which minimize trial and error, (iii) organized cooperation to support fishermen by volunteers, citizens, enterprises, specialists and local governments, (iv) useful viewpoints for detecting decrease of seaweeds and finding critical factors in recovering seaweed beds, (v) explanation of each technique systematized as a flow chart, (vi) promotion of effective use of herbivores to remove them from the habitat and so on.

Key words : guideline, barren ground, isoyake, adaptive management, herbivorous fish, sea urchins

Isoyake recovery project

Seaweed beds provide marine life with food sources and habitat, including breeding and nursery grounds, thus they are important communities to maintain fishery resources. However, reduction of seaweed beds called 'isoyake' has become a serious problem in most coastal prefectures in Japan. It is said that the area of seaweed beds that have disappeared are more than thousand hectares.

To restore seaweed beds, Fisheries Agency carried out a national project in cooperation with 16 prefectures and 19 specialists from fiscal 2004 to 2006. This project reviewed restoration attempts for isoyake reported in previous literatures, and tested them with some newly developed techniques in the field. In addition, various issues on isoyake were discussed at 2 national conferences and 2 local committees in a year. As a summary of the review and these meetings, the Isoyake Recovery Guideline was published in February 2007 (Fisheries Agency, 2007).

Concept of guideline

It has long been said that there are various factors causing isoyake including elevation of water temperature, and decrease of nutrients. (Kuwahara *et al.*, 2006a). According to the questionnaire survey to local government in 2005, reduction of seaweeds was reported from most of the coastal prefectures and overgrazing by herbivores (sea urchins and/or herbivorous fishes) is the most common causative agent of isoyake (Kuwahara *et al.*, 2006b). Therefore, the major theme of the guideline is how to control grazing by herbivores.

Fig. 1 illustrates the situation of isoyake in Japan. When grazing on seaweeds by herbivores exceeds the growth of seaweeds, the balance will incline clockwise leading to isoyake. The clockwise

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movement of the balance may be strengthened by other changes in backgrounds such as global warming and anthropogenic destruction of marine resources. In the unbalanced situations, disappearance of seaweeds and the consequent barren state will enlarge and maintain for a long time. Though the algal growth and grazing should be rebalanced essentially by improving the background conditions, we have few specific methods for the improvement at present. Therefore, though restoration of seaweed beds should be started from accessible areal size such as 100m × 100m, this guideline shows the effective and efficient methods to recover seaweed beds by decreasing herbivores and by increasing seaweed production.

Adaptive management in recovery from isoyake

In this guideline, adaptive management is introduced. This approach consists of eight sections from A to H (Fig. 2). In section A, the occurrence of the isoyake is detected and diagnosed. If the character of isoyake is enumerated, we proceed to Section B where the factor(s) inhibiting seaweed bed formation is identified using simple experiments or surveys in the field. In section C, the goal of the recovery is set with the reference of records of seaweed bed distributions in the past. In section D, methods to remove or alleviate the inhibiting factor identified in section B are examined. In section E, some practical techniques are selected, with the aid of a systematic flow chart of techniques. In section F, restoration is carried out using the technique on the target barren ground. The techniques should be selected considering social contexts in the fishermen's community because of easiness to repeat. After the action, as denoted in section G in Fig. 2, it is necessary to monitor the successional changes on the treated barren ground. Results obtained from monitoring are assessed through section H where the data is compared with the goal of the plans in section C. If the achievement of the goal is confirmed, the new goal should be aimed by starting from section C. If the goal has not been achieved yet, restarting from section B is needed to clarify the reason of the failure. After the reason was clarified, the new approach can be started.

Cycles of trials and monitoring to establish the adaptive learning and feedback control in the restoration of seaweed beds, and they give us valuable information on further management for rocky shore ecosystems.

Flow chart of processes in isoyake recovery

Fig. 3 shows a flow chart of processes sections from A to H. This flow chart helps us to find techniques to minimize the cost and labor of

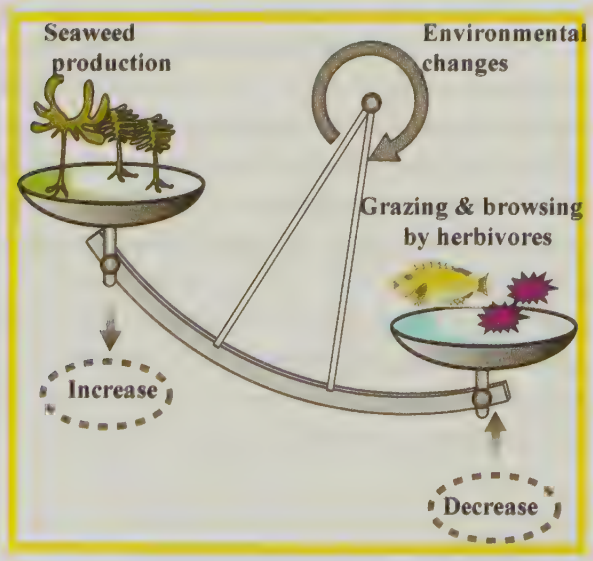


Fig. 1. Situation of isoyake in Japan.

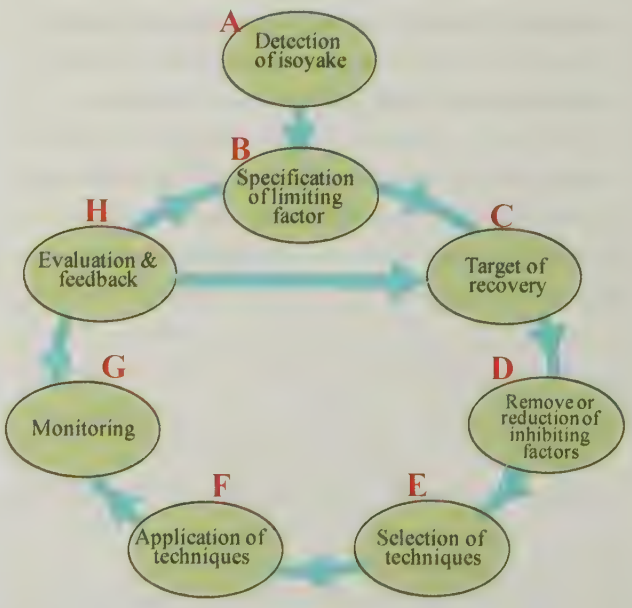


Fig. 2. Adaptive management in isoyake recovery

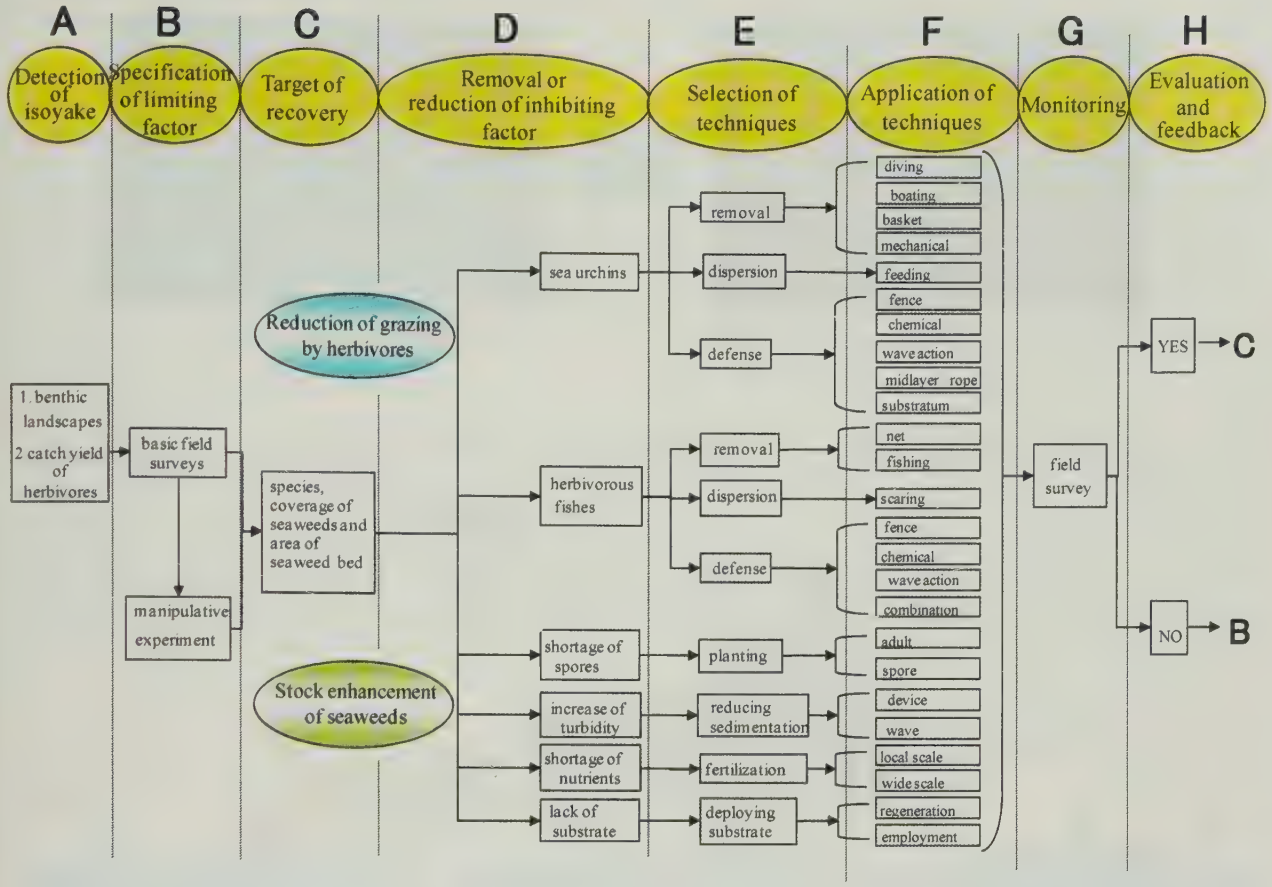


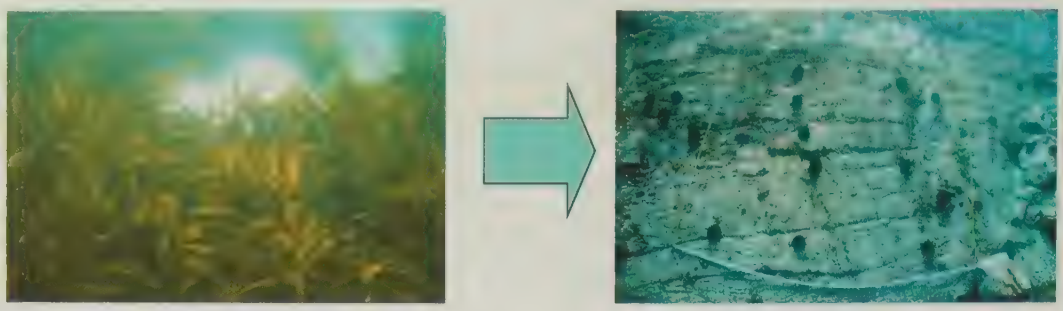
Fig. 3. Flow chart of processes in isoyake recovery

required for trial and error. The techniques were categorized into 25 groups according to their characteristics;. These techniques were extracted from a database with more than 1000 papers in domestic journals on restoration of seaweed beds published from 1970 to 2005 (Kuwahara *et al.*, 2006c). The flow chart is composed of two main branches; reduction of grazing by herbivores and stock enhancement of seaweeds. The former main branch was divided into two branches, for sea urchins and for herbivorous fishes, which are comprised of 10 and 7 techniques, respectively. In each branch, the techniques are categorized into 3 groups, removal, dispersion and defense. The latter main branch is composed of 8 techniques categorized into 4 groups, planting, reducing sedimentation, fertilization and deploying substrates.

Detection of isoyake

Fig. 4 shows section A that proposes two diagnostic methods for isoyake. The first method is the detection from benthic seascapes recorded at the fixed monitoring site every year. The pair of photos (Fig. 4a, b) taken in Ofunato district, Iwate Prefecture, is an example that shows isoyake caused by sea urchins. Photos taken on the sea area will give us valuable information about not only the presence or absence of isoyake but the process of deterioration of the seaweed bed. The second method is the use of statistical data of seaweed and/or and the related herbivores. The figure (Fig. 4c) shows the relationship between catch yields of a canopy forming kelp, *Eisenia arborea* and abalones (*Haliotis* spp.) in Hainan district, Shizuoka Prefecture. Catch yields of *E. arborea* decreased in the 1990's and followed by the depletion in catch yields of abalone. However, each fluctuation cannot

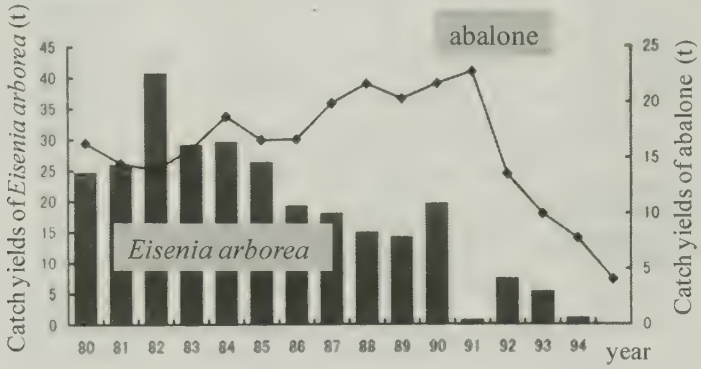
1. Using data of benthic landscapes (Ofunato district in Iwate Prefecture)



a) *Eisenia bicyclis* bed before deforestation (October, 2001)

b) Persistence of urchin barren (October, 2003)

2. Using statistic of catch amount (Hainan district in Shizuoka Prefecture)


abalone
Eisenia arborea
Catch yields of Eisenia arborea (t)
Catch yields of abalone (t)
year
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94

c) Relationship between *Eisenia arborea* and abalone

Fig. 4. Two methods for detection of isoyake

be easily reverted as shown in the Fig. 4c.

Specification of limiting factor for reforestation

In section B, the factors inhibiting growth of seaweeds should be specified. At first, basic field surveys should be carried out using cross-shore observations and the profile of sea bottom, characteristics of sediment, spatial distribution, species composition, coverage of seaweeds and density of herbivores (the top figure of Fig. 5). Through the survey, the limiting factor can be speculated. Otherwise manipulative experiments should be planned. The bottom figure of Fig. 5 shows an example of a cage experiment. Two groups of seaweeds are transplanted on the experimental barren ground; one is protected from grazing by herbivores with the cage, the other is exposed to the grazers. If seaweeds in the cage remain while seaweeds outside disappear, grazing

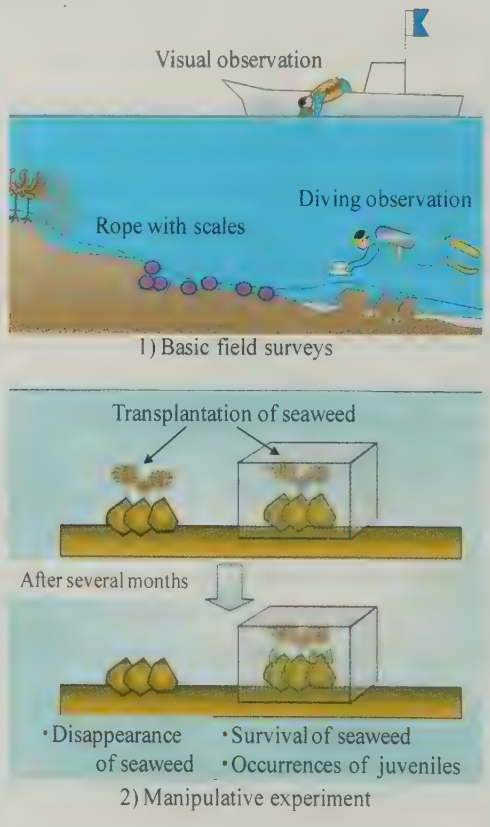


Fig. 5. Specification of limiting factors

by herbivores can be one of the inhibiting factors. In addition, this experiment provides us some other useful information. If seaweeds never deteriorate after transplantation, one can infer that ambient water conditions including nutrients and light have hardly affect growth of the seaweeds. Furthermore, if juveniles of the target seaweed appear within the cage, supply of seaweed spores can be confirmed. It is important to find out the limiting factors for seaweeds before one decides immediate countermeasures for isoyake.

Techniques to control grazing by sea urchins

Fig. 6 shows techniques to control the density (hence grazing pressure) of sea urchins. These techniques are categorized into 3 groups, removal, defense and dispersion.

Removal includes capture by divers, collecting from boat, baskets and pump. Removal by diving is the most efficient among the 4 techniques, but it also requires much labor and cost. Removal by boating and basket needs skill and is difficult to remove sea urchins hiding under stones. Removal by pump is to be developed because of its easiness for handling and low cost.

Defenses include rope, fence, increase of flow velocity and improvement of substrata. The suspended rope is effective along exposed coasts because sea urchins are shaken off by wave action. For enclosure, fence such as loosely folded or buoyed gill nets are used. Furthermore, changing their position is also the way that destabilize footholds for sea urchins. But biofouling and destruction by

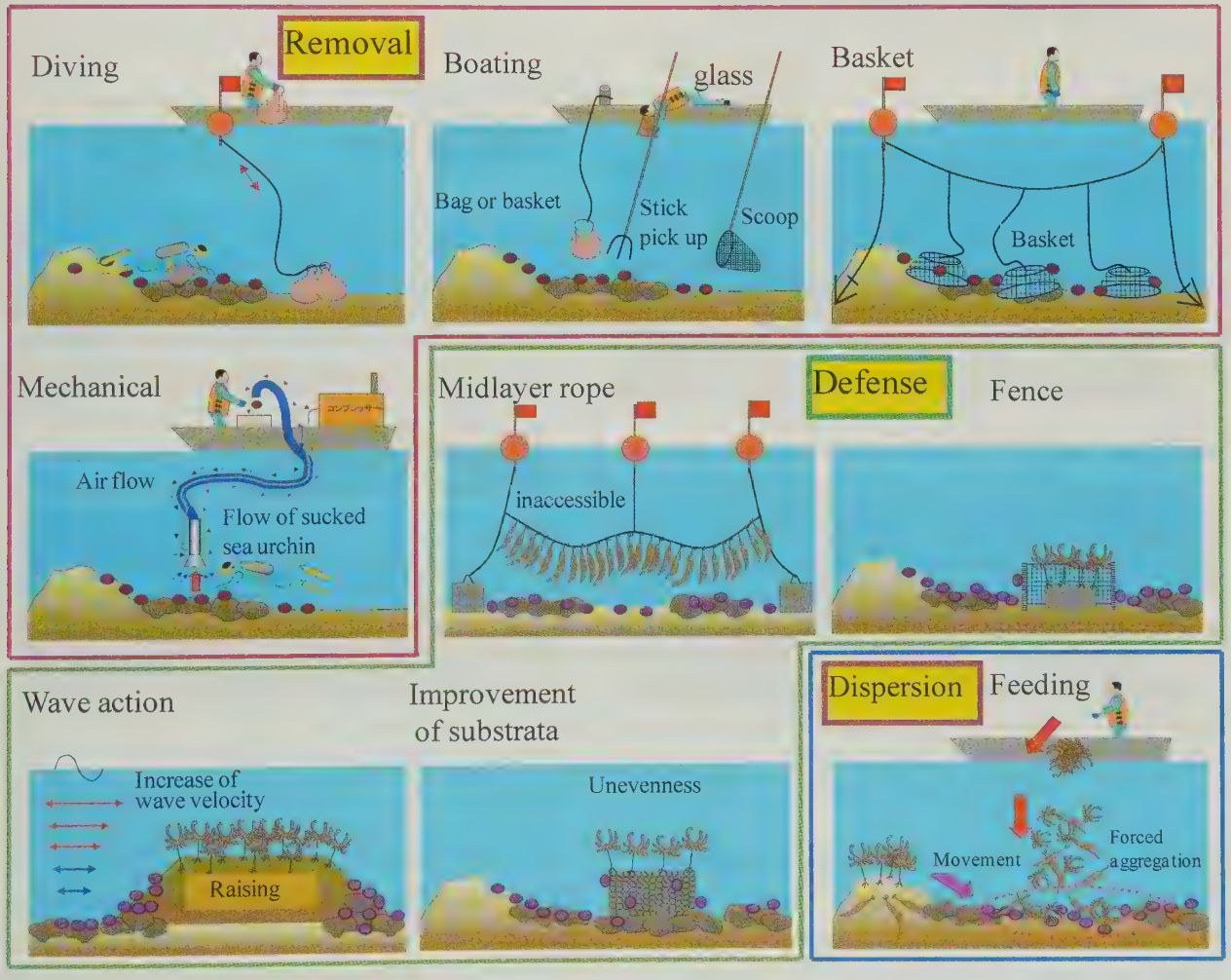


Fig. 6. Techniques to control density of sea urchins

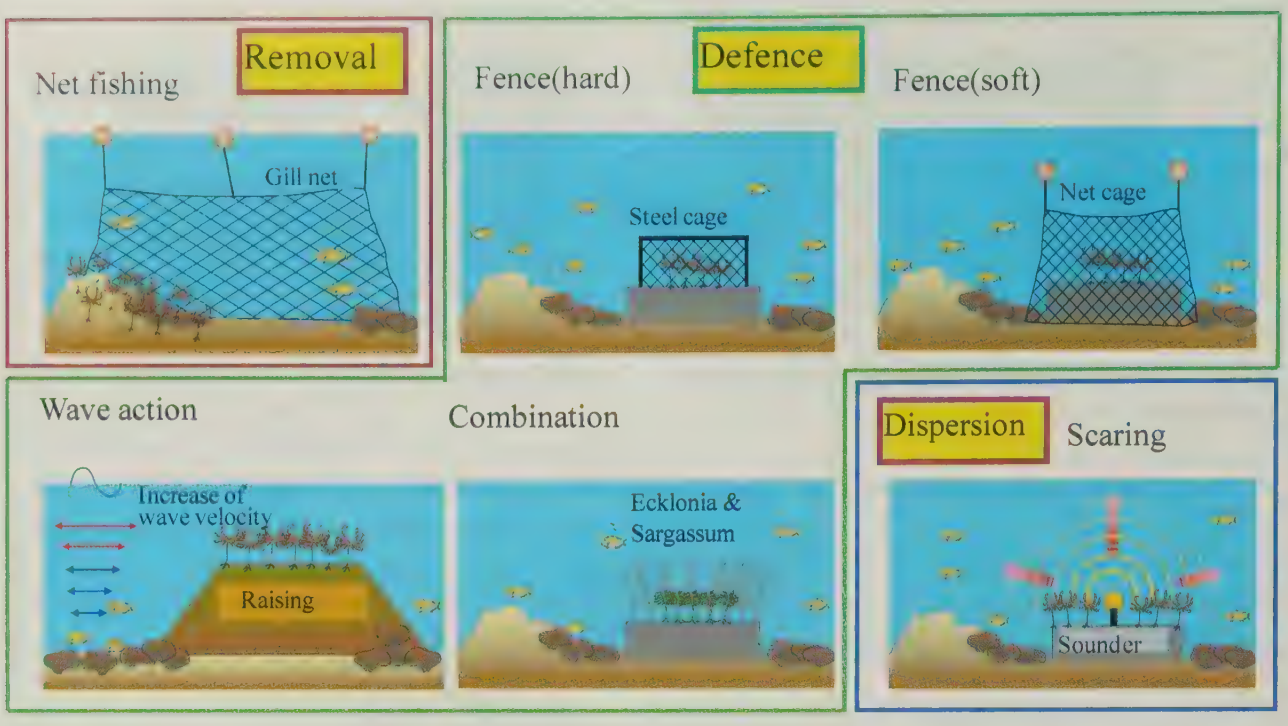


Fig. 7. Techniques to control grazing by herbivorous fishes

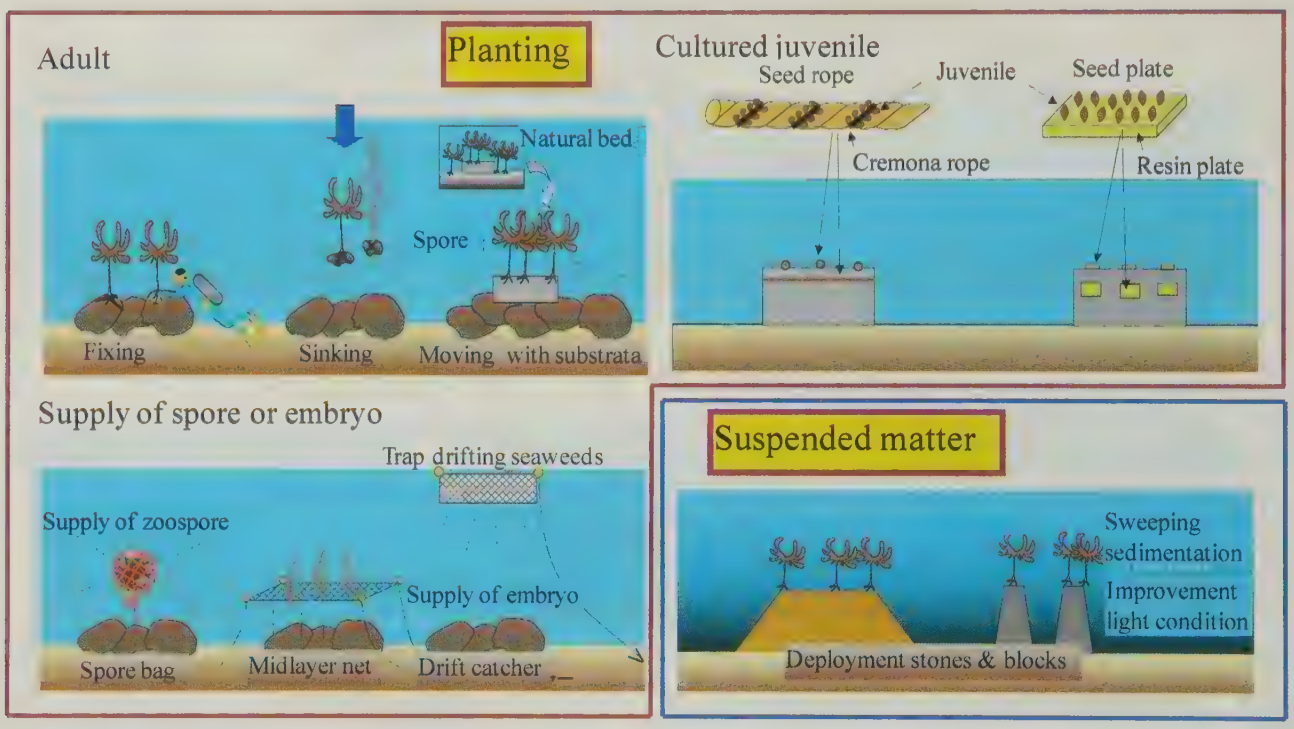


Fig. 8. Techniques for stock enhancement of seaweeds

waves disable long-term use of this method. The elevation of the bottom level using blocks or stones enhances the wave action on them. Enhanced wave motions suppress feeding activity of sea urchins and help seaweed grow. The relationship between the wave action and feeding activity of sea urchins is discussed by Kawamata in this issue. The improvement of substrata is a way to modify

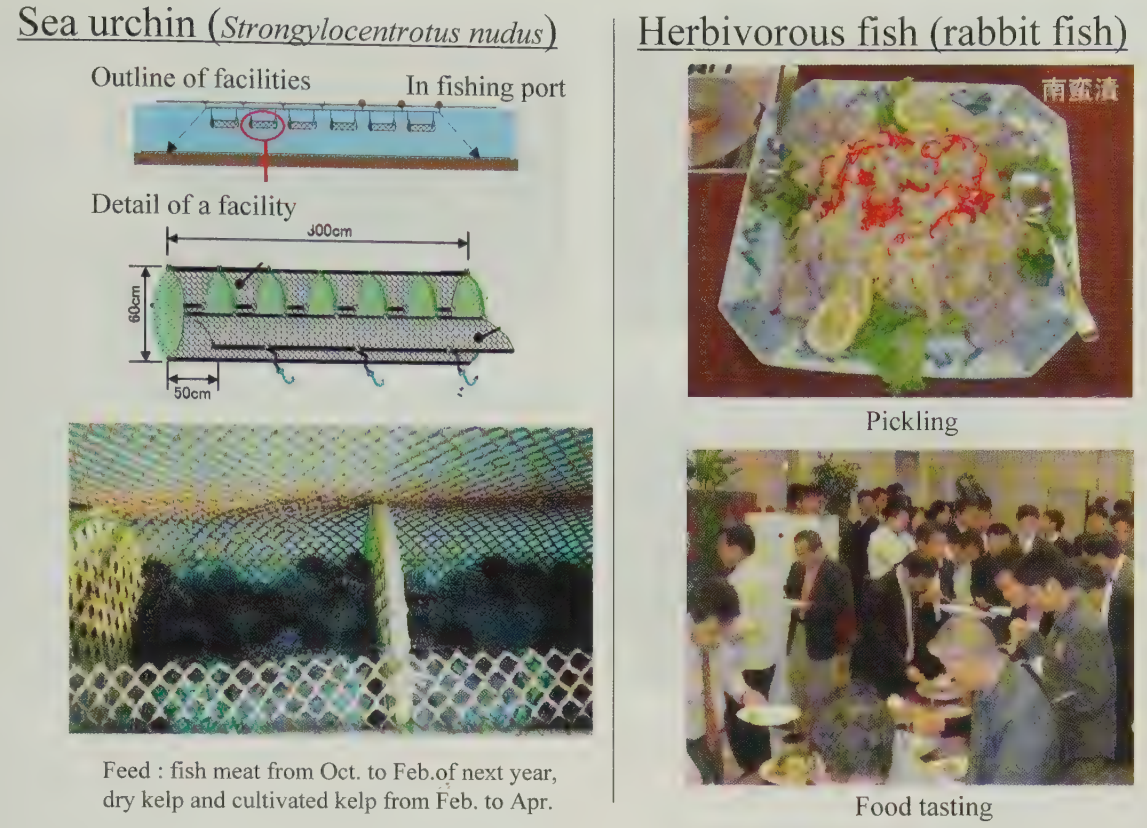


Fig. 9. Examples of effective use of herbivores

the surface microtopography of stones or blocks to increase the refuge of seaweed juveniles.

Dispersion is used to decrease the density of sea urchins by loosening their aggregations by feeding harvested seaweeds.

Techniques to control grazing by herbivorous fishes

Fig. 7 shows techniques to control grazing by herbivorous fish. Removal includes capturing with gill net, fixed shore net and fishing. Herbivorous fishes have often been recorded among the by-catch in net fishing (Akiyama, 2007). Recently, the active removal of herbivorous fishes has been started by fishing. Defenses include fences, increase of flow velocity and combination. Seaweeds in the fence are protected from browsing by fishes. However, the seaweed beds cannot extend out of the fence. Therefore, further improvement is needed to enable seaweeds to grow outside the fence. The combination is a trial to transplant the target on seaweed species with other species. According to information from divers, herbivorous fishes feed much more on seaweeds in uni-algal population than in multispecies communities. Studies about selectivity on seaweed species in herbivorous fishes were started recently. Dispersion is a method that keeps fish away from the seaweed bed by generating blast noises in the water. Wakayama Prefecture Fisheries Experiment Station is developing this method (Yamauchi *et al.*, 2006). Browsing by herbivorous fish has been known for more than a century but has become serious only recently in Japan. Ecological information is not enough to develop effective control of herbivorous fishes. The latest information on herbivorous fishes is shown by Yamaguchi in this issue.

Techniques for stock enhancement of seaweeds

Fig. 8 shows techniques for stock enhancement of seaweeds. Planting includes transplantation of adult seaweeds, supply of spores and embryos and

Fig. 10. Examples of the activity by Shiriya Fisheries Cooperative in Aomori Prefecture.

Fig. 11. Examples of the restoration activity by Nagoya Fisheries Cooperative in Oita Prefecture

cultured juveniles. In the transplantation of adult seaweeds, fixed adult seaweeds with adhesive anchors on the bottom. The simpler method is to throw adult seaweeds with weights from the sea surface. Cultured juveniles are transplanted with ropes or plates where embryos of seaweed grow. Supply of spores or embryos includes mesh bag with adult seaweeds, middle layer net with seaweeds and catcher of drifting seaweeds floated near the sea surface. This method is explained by Yatsuya in this issue. The influence of sedimentation and/or suspended particles has been reported in some bay and inland waters, and is becoming more serious recently. Removal of suspended particles may be needed to decrease light attenuation in the water, but the sources and pass way of the particles should be clarified to reduce the inflow.

Effective use of herbivores

Utilization of herbivores caught by fishermen is very important for the effective and sustainable management of the wild and restored seaweed beds. The left of Fig. 9 is an example of simple pen-culture in a fishing port for sea urchins removed from urchin barrens. This example has been carried out at Setana district in Hokkaido. At the beginning of the culture, sea urchins are fed with meat of fish *Pleurogrammus azonus* caught abundantly in this region, and then cultivated kelps are given to enhance their flavor. Sea urchins reared in this method mature faster than wild individuals; therefore their gonads can be sold at a good price early in the season.

In Japan, custom of eating herbivorous fishes are limited to local areas. The right of Fig. 9 shows a party for sampling the taste of rabbit fish *Siganus fuscescens*. In general, rabbit fish is disliked because of the distinctive smell of the fish meat and a toxic spine in their dorsal fins. However, the dishes of rabbit fish had good evaluation when cooked well without damaging the viscera in the sampling party. To popularize the taste for its commercialization, more sampling parties should be organized.

Practice of Isoyake recovery guideline

Our project team travelled all over the country to inform people about the guideline and to encourage them to practice the procedures given in the guideline. The core of this activity is giving adequate technical support to fishermen who are trying to start restoration of seaweed beds in isoyake area. This activity has been carried out in about 15 areas, where fishermen positively work on recovery from isoyake. In each area, a local consultation group was organized to decide the plan. In this group, practitioners of local government and scientific experts were included. We started new attempts in which that fishermen work together with people from other sectors such as universities and high schools. This practice is explained by Taino in this issue.

Fig. 10 shows an example of the activity by Shiriya Fisheries Cooperative in Aomori Prefecture. In this area, 1-3 hectares per year of kelp (*Saccharina japonica*) beds have been recovered since professional divers employed by fisherman carried out removal of sea urchins. In 2008, fishermen manifested the removal of sea urchins for themselves. Therefore, they were trained to use dry suits and to practice removal of sea urchins. They managed to implement a large-scale sea urchin removal project.

Fig. 11 shows the case of Nagoya Fisheries Cooperative in Ohita Prefecture. Seaweed bed in this region has been heavily grazed by both sea urchins and herbivorous fish. The fishermen made cages to protect seaweed from fish grazing and fences to protect from herbivorous fish. In this area, there are a lot of fishermen divers because they use SCUBA diving gears in their daily jobs. Therefore, they could complete sea urchin removal by themselves and they set nets and cages on the sea bottom.

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水研センター研報，第32号，61－67，平成22年
Bull. Fish. Res. Agen. No. 32, 61-67, 2010

Different effects on seaweed succession after sea urchin removal at several coastal waters in Tosa Bay, southern Japan

Seiya TAINO [*1]

Abstract : The effectiveness of sea urchin removal for the purpose of regenerating the seaweed bed was studied at several study areas in Tosa Bay. Marine algal succession and density of invaded sea urchins after sea urchin removal were examined at five stations (Kamikawaguchi, Kutsuu, Ikenoura, Tei and Sakamoto). Large perennial algae superseded coralline algae at Kamikawaguchi, Kutsuu and Ikenoura, since the inhibiting factor was removed by sea urchin removal by scuba diving. Furthermore, spores and embryos, tided from near seaweed beds to study area, accelerated regeneration of seaweed bed. On the other hand, seaweed beds have not regenerated after sea urchin removal by SCUBA diving at Tei and Sakamoto, In these stations, it appears that both the feeding activity of sea urchin and the browsing activity of herbivorous fishes inhibited marine algal succession. Fishermen and students removed sea urchins by skin diving at Kamikawaguchi and Kutsuu in 2007. It should be noted that even the skin diving removal of sea urchin have an effect on regeneration of seaweed bed.

Key words : Isoyake, sea urchin removal, *Anthocidaris crassisspina*, *Echinometra* spp., *Sargassum micracanthum*, *Sargassum siliquastrum*, *Ecklonia cava*

The first step to recovery of seaweed bed

The barren grounds 'Isoyake' exist along the coasts of Kochi Prefecture, Japan. In the Isoyake areas in Kochi Prefecture, *Anthocidaris crassisspina*, *Echinometra* spp. and *Echinostrephus molaris* dominate on bedrock and boulders.

The first approach of sea urchin removal in Kochi Prefecture started at Kamikawaguchi in 2002 (Fig. 1). The experimental area was a hectare in area. It took nine days and twenty-seven divers cumulatively to remove all sea urchins in the experimental area. Sea urchins were crushed in the water by using iron sticks, because there were no edible sea urchins. The estimated number of removed sea urchins was approximately 74,000 individuals. The coverages of large perennial algae (*Sargassum micracanthum*, *S. siliquastrum* and *Ecklonia cava*) were examined at thirteen stations by using a quadrat from December 2002 to February 2008. Also the density of invaded sea urchins after sea urchin removal were studied at four stations (St.1, 2, 3 and St.4 or St.4') by quadrat sampling from December 2002 to February 2008 (Fig. 2). According to field surveys at Kamikawaguchi, the deviation of *Echinometra* spp. which assumed the density of *Echinometra* spp. in preliminary survey was 0 have ranged from -9.3 to 0.3 ind. / m^2 in St.1 and St.2 during survey period. On the contrary, the density of *Echinometra* spp. in St.3 frequently exceeded that before removal (Fig. 2). *S. micracanthum*, *S. siliquastrum* and *E. cava* grew in shallow water superseded coralline algae within a year of the sea urchin removal. After six years, the coverage of *E. cava* became higher than that of *S. micracanthum* and *S. siliquastrum* (Fig. 3).

The second sea urchin removal carried out at Ikenoura (Fig. 1) in 2006 (Taino *et al.*, 2008). The experimental area was half of a hectare in area. It took seven days and forty-two divers cumulatively to remove all sea urchins in the experimental area.

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The number of removed sea urchins was 150,034 individuals. Sea urchins were crushed by the same way as above. The density of invaded sea urchins after sea urchin removal were studied at four stations (St.1, 2, 3 and St.4) by quadrat sampling from June 2006 to March 2008. The deviation of *A. crassisspina* and *E. molaris* described above have been negative value within experimental area (St.1, St.2 and St.3) during the survey period. On the contrary, the density of *Echinometra* spp. occasionally exceeded a reference value (Fig. 4). The coverages of large perennial algae, *S. micracanthum*,

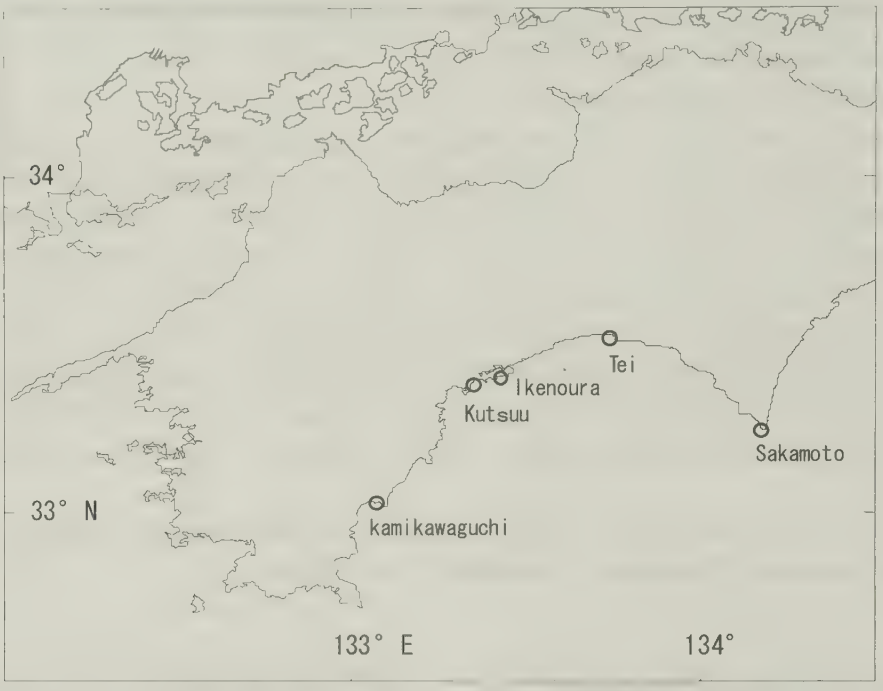

Fig. 1. Map showing five study sites of sea urchin removal along the coast of Tosa Bay, Kochi.

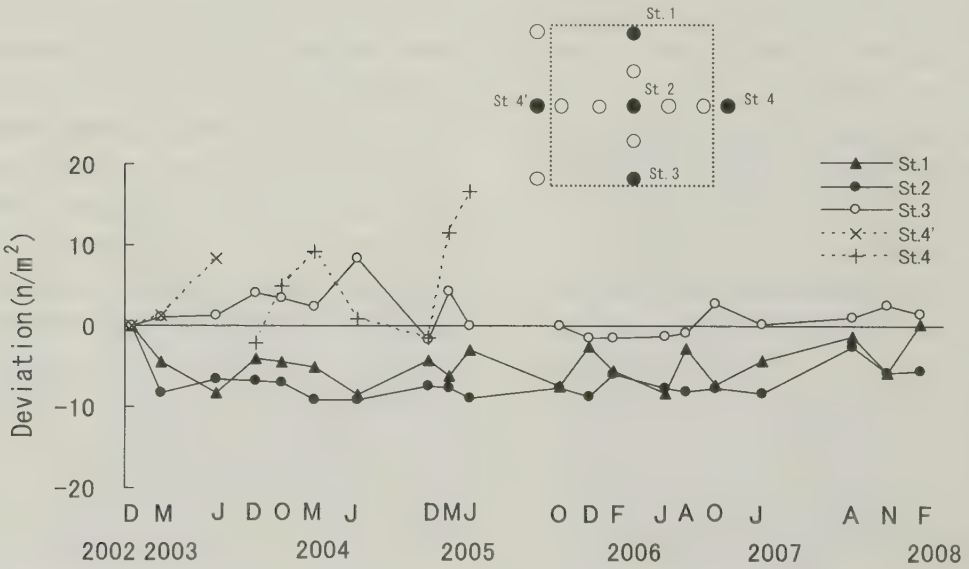

Fig. 2. Seasonal variations of the deviation of *Echinometra* spp. at St.1-3 (December 2002 to February 2008) and St.4 (December 2002 to July 2003) and St.4' (December 2003 to July 2005) in Kamikawaguchi. Simplified drawing on top showing the stations of coverage observation (open and solid circles) and quadrat sampling (solid circles).

were examined at twenty-eight stations (Fig. 5) by using a quadrat from June 2006 and December 2007. Our observations show that the shallow water. *micracanthum* population existed before sea urchin removal colonized the Isoyake area in December 2007.

Difficult situations which show few signs of a recovery of seaweed bed

The third experimental site, Tei, is located in the central part of Tosa Bay (Fig. 1). Extensive *E. cava* population has been existed from 1980's to early 1990's. A large number of researches (Ohno and Ishikawa, 1982; Serisawa *et al.*, 2001; Serisawa *et al.*, 2002a; Serisawa *et al.*, 2002b; Tominaga *et al.*, 2004) were done in this area. The unbelievable fact that the *E. cava* population disappeared during 1999 to 2000 at Tei was reported in 2000 and 2004 (Serisawa *et al.*, 2000; Serisawa *et al.*, 2004). The approach of regeneration of seaweed bed started in July 2005. There were two experimental areas which was 49,000m^2 in area respectively. It took twenty-nine days and one hundred and twenty divers cumulatively to remove all sea urchins in two experimental areas. The method of removal was same as Kamikawaguchi and Ikenoura. The number of removed sea urchins was 304,356 individuals. Same surveys as above were carried out at Tei from July 2005 to February 2008. The density of *Echinometra* spp. has been at a low level within experimental area during survey period. On the contrary, the density of *A. crassisspina* exceeded a reference value obtained before removal. At these experimental areas, the Gelidiaceae community, which was observed before the removal of sea urchins, broadened. Otherwise, large perennial algae have never appeared during survey period. Now we are trying a spore bag method (Serisawa *et al.*, 2005) to regenerate large perennial algae (e.g., *Sargassum* and *Ecklonia*).

Forth study site, Sakamoto, is located in the eastern part of Tosa Bay (Fig. 1). The experimental area was a hectare in area. It took six days and forty-three divers cumulatively to remove all sea urchins in the experimental area. The number of removed sea urchins was 227,262 individuals. Sea urchins were crushed by the same way as above. Same surveys described above were carried out at Sakamoto from August 2006 to February 2008. After sea urchin removal, small annual and small perennials, increased here, but large perennials never appeared. In this station, only *Dictyopteris undulata* colonized in November 2007. There are many herbivorous fishes in this experimental area, and there were many white spots which were traces of scraping

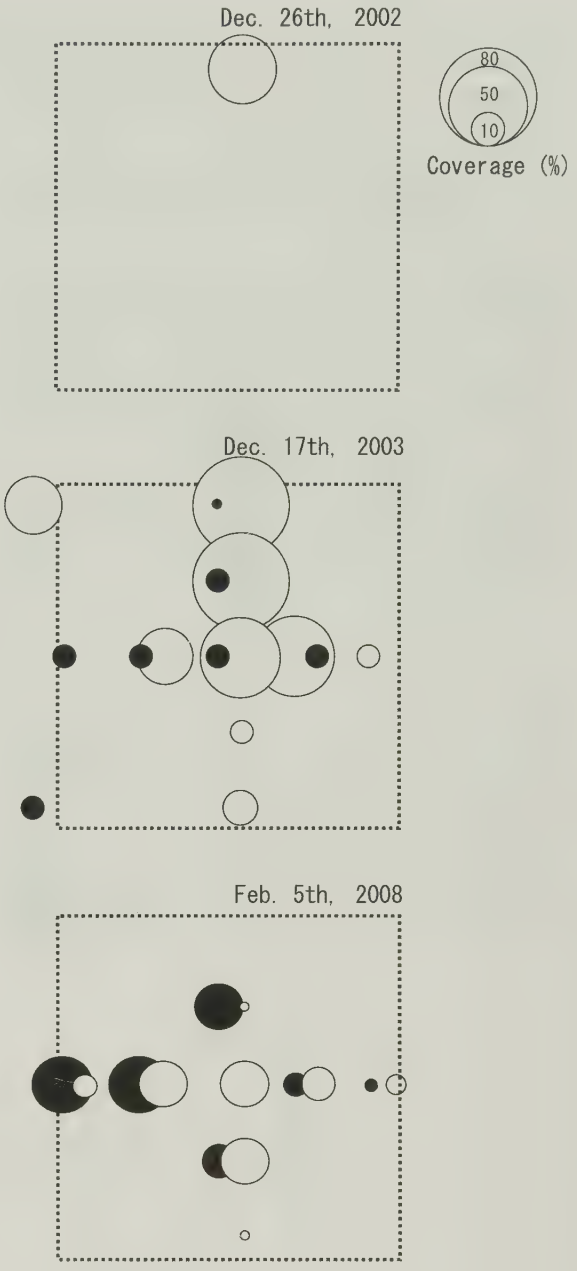

Fig. 3. Changes in the coverage of *Sargassum micracanthum*, *S. siliquastrum* (open circles) and *Ecklonia cava* (solid circles) at Kamikawaguchi.

by *Scaridae* fishes. It appears that both the feeding activity of sea urchin and the browsing activity of herbivorous fishes inhibited marine algal succession.

New approach of cooperative activity with fishermen, students and volunteers

Fishermen and students removed sea urchins by skin diving at Kutsuu in June and October 2007 (Fig. 1, 6). After six months, many juveniles of *Sargassum yamamotoi* has been appeared, and then they grew up in April 2008.

Thirty fishermen removed sea urchins by skin diving at Kamikawaguchi in August 2007 (Fig. 1). The experimental area was a hectare in area. The sea urchin removal carried out during three days and eighty-two divers engaged cumulatively in removal of sea urchins in the experimental area. The sea urchins were crushed in the water. The number of removed sea urchins was estimated approximately 68,000 individuals which were 40% of their total composition in the experimental area. After seven months, many juveniles of *Sargassum* spp. appeared in the experimental area. It should be noted that even the skin diving removal of sea urchin have an effect on regeneration of seaweed bed.

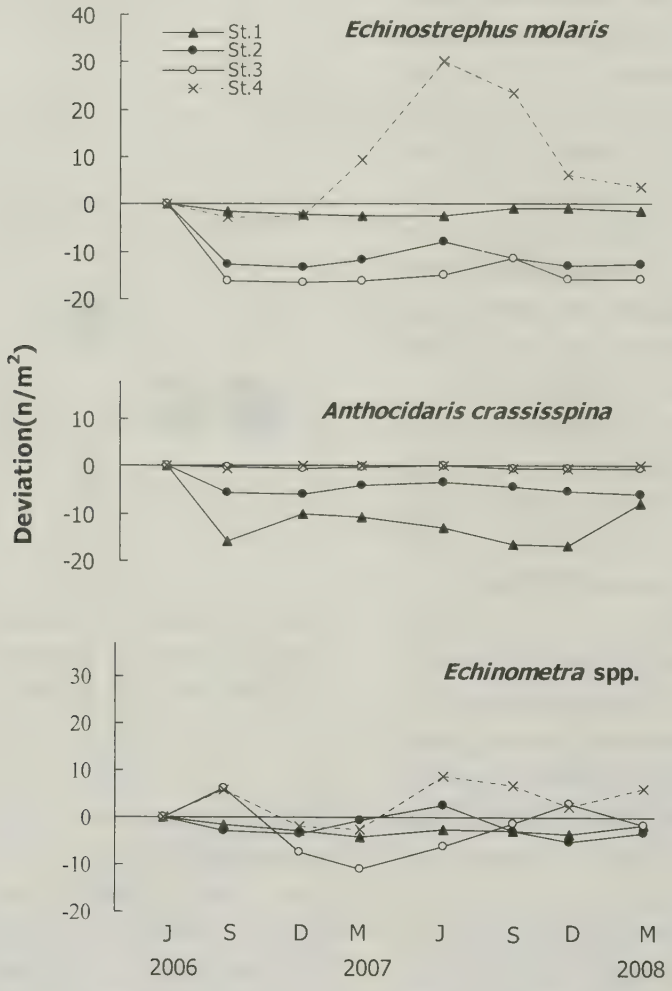

Fig. 4. Seasonal variations of the deviation of *Anthocidaris crassisspina, Echinostrephus molaris* and *Echinometra* spp. at Ikenoura from June 2006 to March 2008.

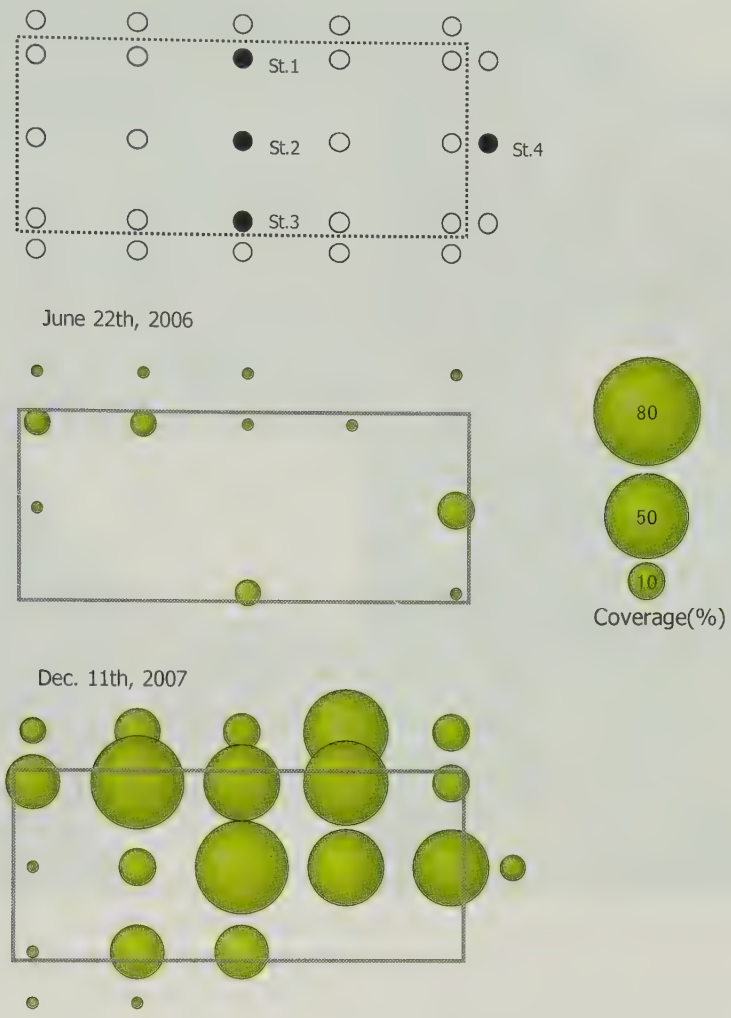

Fig. 5. Changes in the coverage of *Sargassum micracanthum* at Ikenoura. Simplified drawing on top showing the stations of coverage observation (open and solid circles) and quadrat sampling (solid circles).

The case examples of marine afforestation by sea urchin removal were reported in Hokkaido (Agatsuma *et al.*, 1997; Kuwahara *et al.*, 2001; Kawai *et al.*, 2003; Kawai and Tajima, 2003) and Nagasaki Prefecture (Yotsui and Maesako, 1993). At Kamikawaguchi, after two weeks from removal of sea urchins, rocky bottoms were covered by attached diatoms in experimental area. In the next March, *Colpomenia sinuosa* and juvenile thalli of *Sargassum* spp. appeared densely on rocky bottoms. Maximum biomass of *Sargassum* bed (5.2 kg wet wt / m^2) was recorded in December 2003. Thus, attached diatoms, small annual algae and large perennial algae colonized in the Isoyake area, successively. In this report, we carried out sea urchin removal at five experimental areas. And now there are five kinds of result. Sea urchin removal is most effective method to regenerate seaweed bed at Kamikawaguchi, Kutsuu and Ikenoura. Although at Tei and Sakamoto, we must develop strategies for the browsing activity of herbivorous fishes in addition to the feeding activity of sea urchin. Furthermore, I would like to go on to develop the management of cooperative activity with fishermen, students and volunteers.

Fig. 6. Photographs showing the cooperative activity with fishermen, students and volunteers. Meeting with students before sea urchin removal at Kutsuu (A), Skin diving removal of sea urchin at Kutsuu (B), Student crushed sea urchins in the water by using iron stick at Kutsuu(C), Commemorative photograph of the first cooperative activity of afforestation at Kutsuu(D).

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Techniques for the restoration of *Sargassum* beds on barren grounds

Kousuke YATSUYA [*1]

Abstract : On barren grounds formed after deforestation, supply of propagules is often limited due to the long distance from existing seaweed beds. However, drifting thalli of *Sargassum* can reproduce and introduce embryos even on barren grounds. In order to investigate whether drifting *Sargassum* can effectively supply embryos, the abundance and fecundity were investigated in thalli entangled around floating ropes of a set net in western Wakasa Bay, in the Sea of Japan. Biomass of the entangled drifting *Sargassum* was the highest in late May. Drifting thalli of *Sargassum patens* and *S. macrocarpum* were found to release comparable numbers of embryos to those growing in seaweed beds. The following year, an artificial reef was deployed in the same area, and floating ropes were installed above the artificial reef to entrap drifting *Sargassum*. Six month later, the percent cover of *Sargassum* on the top of the artificial reef was higher around the floating ropes, suggesting that this setup facilitated the effective supply of *Sargassum* embryos. In addition, novel techniques to culture *Sargassum* seedlings were developed. The seedlings can be cultured freely in a transparent aquarium with strong bubbling. It is easy to adjust the density of seedlings in accordance with their size, avoiding density-dependent mortality and growth suppression. We also developed two techniques to fix seedlings to some setups or to the seabed. These techniques using seedling production and aquaculture can be applied for the recovery of *Sargassum* beds on barren grounds.

Key words : *Sargassum*, drifting seaweed, seaweed aquaculture, seedling production, trap

Introduction

Seaweed forests have important roles in primary production and providing nursery grounds, now decreasing along the coasts of Japan. We are trying to generate seaweed forests (particularly *Sargassum*) using drifting thalli and seedling production techniques, which have been developed over the course of artificial reef construction and seaweed aquaculture. This paper introduces these techniques.

Use of drifting seaweed

On barren grounds formed after deforestation, supply of propagules is often limited due to the long distance from existing seaweed beds in the surrounding area. The dispersal ability of *Sargassum* embryos is rather limited compared to that of kelp (Kendrick and Walker, 1991; Reed *et al.*, 1988). However, drifting seaweed of *Sargassum* is able to transport embryos over a long distance. We used drifting seaweed to enhance the supply of embryos onto an artificial reef. This study consists of a preliminary survey and an application for artificial reef construction.

Preliminary survey

For the preliminary survey, the biomass and fecundity of drifting seaweed were investigated. To clarify temporal changes in biomass, drifting seaweed entangled around floating ropes of a set net in western Wakasa Bay, in the Sea of Japan, was investigated on a bi-weekly basis from early May to late July 2005 (Yatsuya *et al.*, 2006). Biomass

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was highest in late May (Fig. 1), reaching to 1.3 kg (wet wt.) per meter of floating rope. Among these seaweeds, *Sargassum patens* and *S. macrocarpum* were dominant (Fig. 1).

Therefore, the fecundity of these species was examined with respect to the difference between drifting thalli and that attached on the substrata in a *Sargassum* bed. Drifting and attached seaweeds were collected within an area of 1 km, and 1.5 kg of thalli was stored in a tank with running seawater. After one week, the numbers of embryos released from the thalli were counted under a microscope.

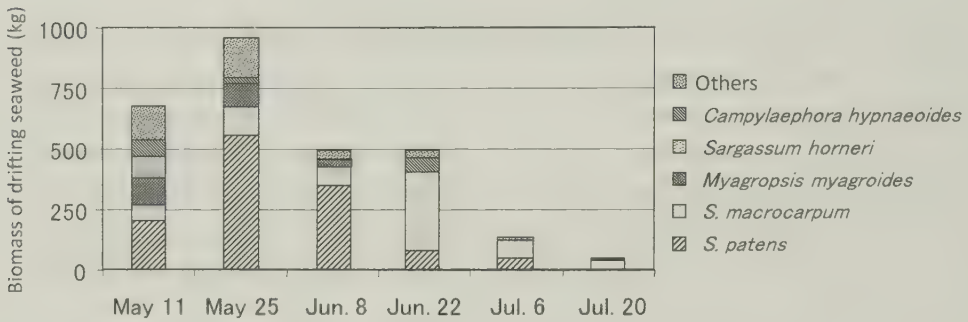

Fig. 1. Biomass of drifting seaweed entangled around floating ropes of a set net in western Wakasa Bay, the Sea of Japan.

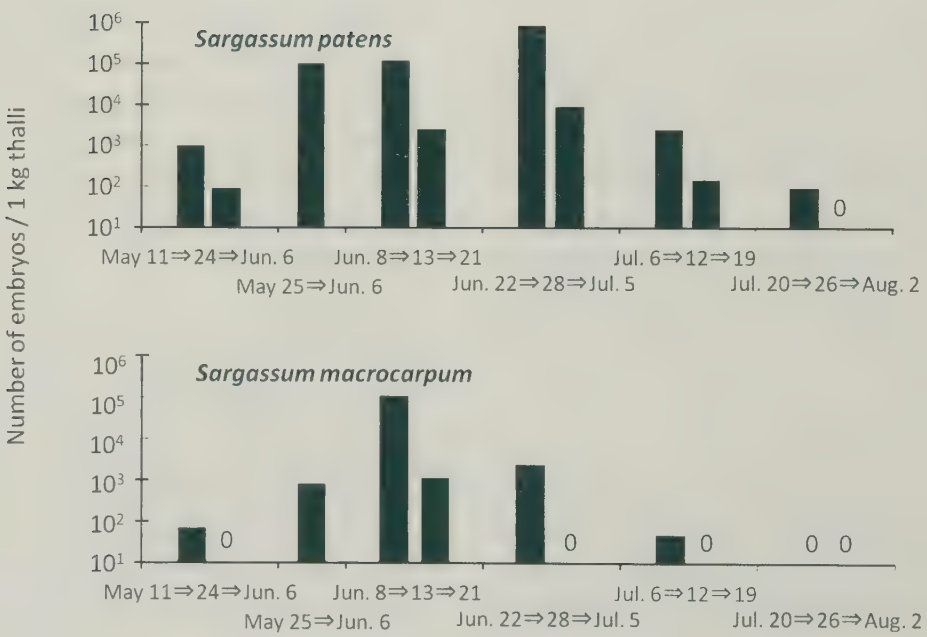

Fig. 2. The number of embryos released from 1 kg of drifting seaweed. N.D. indicates no data.

Sargassum patens and *S. macrocarpum* released at maximum 770,000 and 100,000 embryos per kg of drifting thalli, respectively (Fig. 2). These figures were equal to or higher than those of attached seaweed, suggesting that drifting was comparable to attached seaweed in regard to the number of released embryos.

Application for artificial reef construction

In March of the following year, 7,000 m^2 of artificial reef on a sandy seabed was deployed in the same area investigated in the previous year. It seemed to receive few *Sargassum* embryos due to the lack of a wild *Sargassum* forest in the surrounding area. From April to July, floating ropes were positioned above the artificial reef to entrap drifting *Sargassum* thalli and supply embryos. Since the abundance of drifting *Sargassum* in this year was lower than expected, we collected drifting thalli around the area and manually tied it to the floating ropes.

Six month after construction, the percent cover of *Sargassum* was investigated along a transect line perpendicular to the floating ropes. The cover of *Sargassum* was higher around the floating ropes (Fig. 3), suggesting that this setup effectively supplied *Sargassum* embryos from drifting thalli of *Sargassum* (Yatsuya *et al.*, 2008). This technique was also applied for the restoration of seaweed beds on barren areas around Kyusyu Island.

Seedling production

Seaweed growing in its natural environment shows higher mortality in its early life stage (Chapman, 1984). However, seedling production on land and subsequent transplantation into the sea could reduce the risk of mortality. Therefore, methods of effective seedling production and transplantation into the sea should be developed.

How to cultivate *Sargassum* seedlings

To date, seedlings of *Sargassum* are usually planted on the surface of a hard substratum. These seedlings suffer from density-dependent mortality

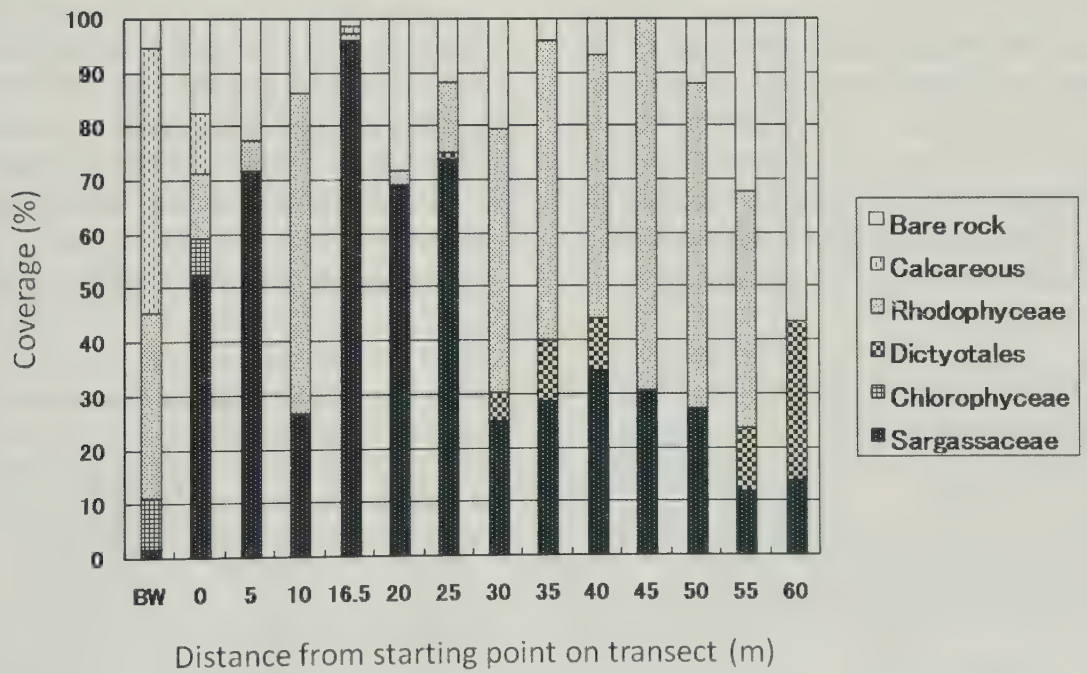

Fig. 3. Percent cover of seaweeds along a transect line on an artificial reef. The floating rope, which trapped drifting seaweed, was installed at 16.5m. BW indicates the foundation of a breakwater along the shallower edge of the artificial reef.

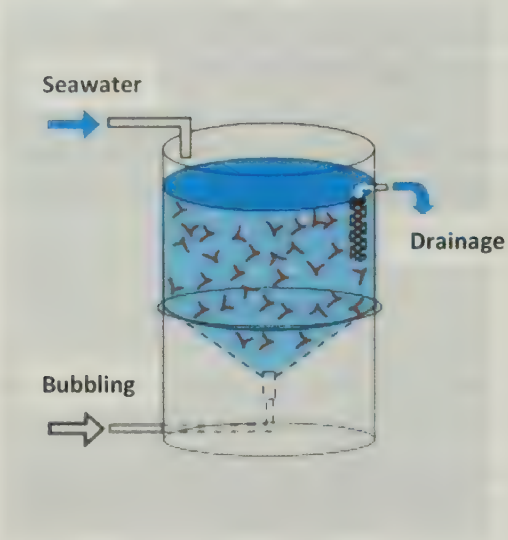

Fig. 4. Schematic drawing of the free culture method.

when they grow and become crowded. We found that *Sargassum* seedlings could be cultured freely in a transparent aquarium with a constant inflow of seawater and strong aeration (Fig. 4). Using this method, it is easy to adjust the density of seedlings in accordance with their size, avoiding density-dependent mortality and growth suppression.

The growth and survival rate of small seedlings with one leaf were compared using two culture methods: one involved free culture in an aquarium, and the other planting on a hard substratum. Both the growth and survival rates of seedlings were higher using the free culture method (Table 1). The density of seedlings also had a significant effect on the growth and mortality rates. The lower the seedling density, the better the growth and survival rates. This new culture method has been applied for seedlings of *Sargassum fulvellum*, *S. horneri*, and *S. patens*.

How to fix seedlings of *Sargassum* in the sea

In this section, two techniques of how to fix *Sargassum* seedlings in the sea are reported. The first method uses a net to which the seedlings are fixed. Each primary branch of the seedling is inserted through the mesh of a net. Then, the net is rolled to encircle the basal part of the seedling, protruding most of the primary branch. The size of the net is usually 5 m long and 20 cm wide and stretched mesh size is 4 cm. Seedlings weve fixed every 10 cm on the net. This line is suspended horizontally at a depth of 1 to 2 m. At this time, the average length of seedlings is more than 20 cm. The seedlings grow from autumn through winter, achieving a length of more than 1 m during the reproductive season in spring of the following year. These thalli are expected to release masses of embryos into the surrounding area (Fig. 5a).

Secondly, we use a tiny substratum attached to seedlings which is cultured freely in an aquarium. The substratum is made of a kind of plastic whose density (i.e., specific gravity) is nearly equal to that of the seawater. The dimensions of the substratum are 1.0 x 1.5 x 1.0 cm. *Sargassum* embryos were sown on the surface of the substratum and cultured in a tank with slowly running filtered seawater for two months. After that, the seedlings growing on the substratum were cultured freely in the same

Table 1. Growth and survival rates of *Sargassum fulvellum* seedlings at various densities using the two culture methods

Method	Cultured freely in aquarium				Planted on a hard substratum
Density of seedlings	25 ind./L	50 ind./L	100 ind./L	200 ind./L	7.5 ind./cm^2
Growth rate* (mg/day)	0.28	0.17	0.14	0.06	0.07
Survival rate (%)	75	79	64	49	20

* Growth rate = $(W_t - W_0)/t$,
where W_t and W_0 are the mean weights of a seedling at t days later and the start of the experiment, respectively. t is the experimental period (days)

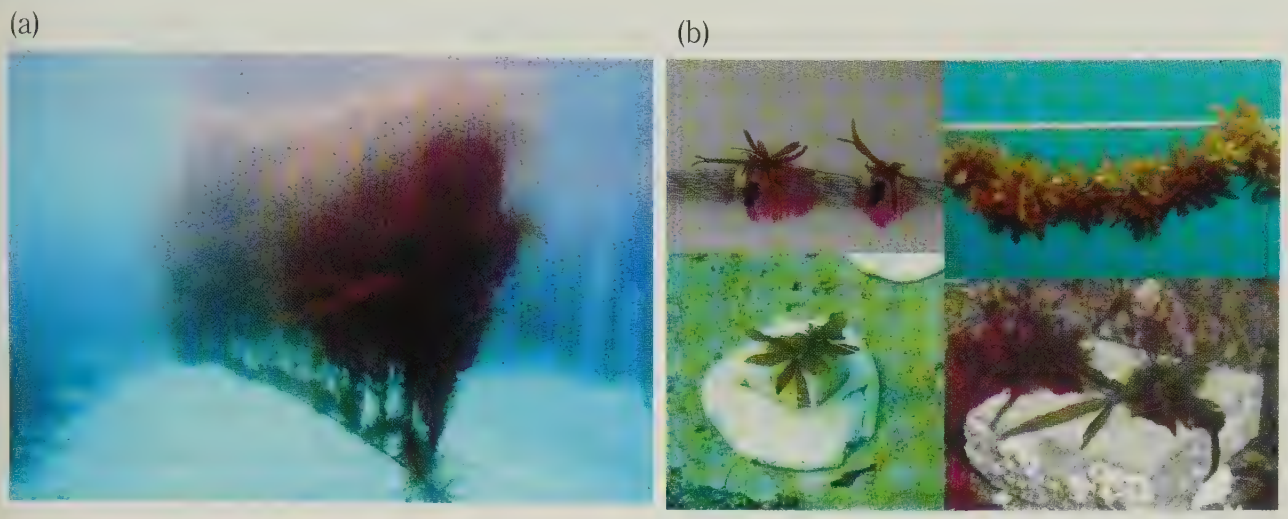

Fig. 5. *Sargassum fulvellum* fully grown in the reproductive period (a), and *Sargassum* seedlings growing a tiny to substratum are fixed in various ways (b).

way in the method mentioned above. When the seedlings were transplanted in the sea, the tiny substrata with seedlings are fixed to some setups or to the seabed in various ways. They can be attached to a rock or concrete block on the sea bottom, or tied to a rope suspended at the target depth (Fig. 5b). This technique made it possible to transplant smaller seedlings which could not be fixed by a mesh net. Therefore, we have been able to culture *Sargassum* seedlings in any season with physically and/or chemically favorable conditions and a lower grazing pressure. These techniques using seedling production and aquaculture can be applied for the recovery of seaweed beds on barren grounds.

Acknowledgment

I am extremely grateful to researchers of Kyoto Institute of Oceanic and Fishery Science who have been devoted to research on seaweed aquaculture and seedling production.

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Reduction of *Eisenia bicyclis* bed by a grazer *Strongylocentrotus nudus* off Oshika Peninsula: as an example of urchin barren in northeastern coast of Honsu, Japan.

Daisuke MURAOKA [*1]

Abstract : The reduction of seaweed beds (Isoyake) has been known nearly all over the country in Japan. In northern Japan, reduction of kelp beds has significant consequences on the local fishing community dependent on the kelp and herbivores such as sea urchins and abalone. Hearing to prefectural governments by Fisheris Agency has shown that the major factor causing the reduction of kelp beds in northern Japan is sea urchin grazing. As an example of a receding kelp bed in the cold temperate waters , I show the results of a local ecological survey of *Eisenia bicyclis* bed and the sea urchin (*Strongylocentrotus nudus*) and abalone (*Haliotis discus hannai*) on the rocky coastal area in Tomarihama of Oshika Peninsula, Miyagi Prefecture (northern Japan). This survey indicated that the high grazing pressure of sea urchins reduced the survival of juvenile *E. bicyclis* sporophytes near the lower limit of the bed, thus impeding the recruitment of juvenile in the area formerly occupied by adult sporophytes.

Key words : grazing, *Eisenia bicyclis*, sea urchins, *Strongylocentrotus nudus*, degeneration, kelp beds, monitoring

Introduction

Seaweed beds play an important role as one of the primary producers in temperate coastal ecosystems; they provide a place for marine animals to spawn and grow, and supply food to herbivores such as sea urchins and abalone (e.g. Dayton, 1985; Steneck *et al.*, 2002). In northern Japan, kelp (Laminariales) including *Saccharina*, *Eisenia* and *Ecklonia* are extensively distributed on rocky coastal areas. Abalone and sea urchins mainly graze kelp, so the reduction of kelp beds has significant consequences to the local fishing community dependent on these resources. In particular, *Eisenia* and *Ecklonia* beds, which account for approximately 20% of the kelp beds extending along the coastline of Japan (Nature Conservation Bureau, 1994), have been recognized as very important kelp beds for the coastal fisheries because of their high productivity and their high food value for sedentary herbivores. On the other hand, *Saccharina* spp. (Kombu in Japanese) beds are very important not only for food of the herbivores but also for human consumption. *Saccharina* spp. is used as one of the main ingredients for *dashi*, the seafood based stock used extensively in Japanese traditional food.

Loss or decline of kelp beds has been reported on a worldwide scale. The main reasons have been considered to be overgrazing by sea urchins (Lawrence, 1975; Elner and Vadas, 1990; Sivertsen, 2006) and by herbivorous fish (Harris *et al.*, 1984). It was reported that on the coasts of Japan, 2,194ha of beds of *Saccharina*, *Eisenia* and *Ecklonia* spp. have disappeared in the 13 years after 1978 (Nature Conservation Bureau, 1994).

Figure 1 indicates the factors reducing seaweed beds along the coast of Japan (Fisheries Agency, 2007). This figure shows the major factor in southwest Japan is herbivorous fish grazing. On the other hand, in northern Japan, the main factor is sea

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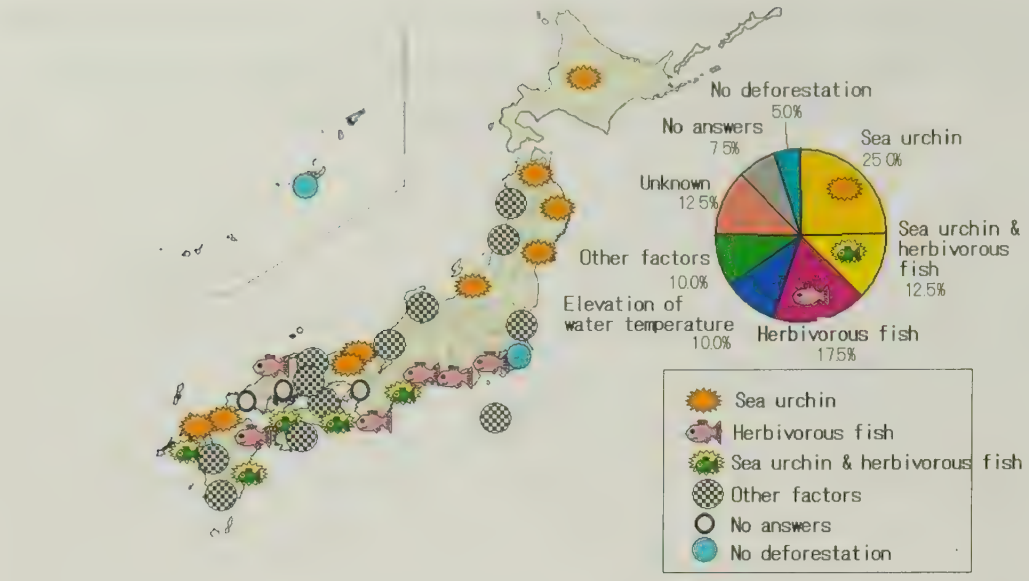

Fig. 1. The factors causing reductions of seaweed beds in Japan (Fisheries Agency, 2007)

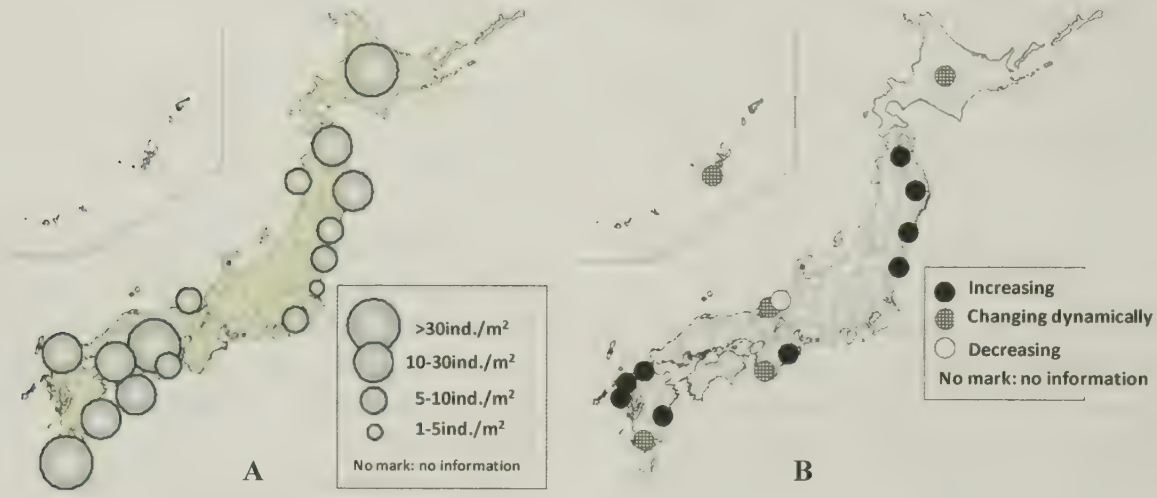

Fig. 2. The densities (A) and the changes (B) of sea urchins in Japan (Fisheries Agency, 2007)

urchins grazing.

Figure 2 indicates the densities (A) and the recent trends of abundance (B) of sea urchins in the rocky coastal areas of Japan. It is clear that the densities remain high (over 5 individuals / m^2) and are increasing in Sanriku Coast, northern Japan.

Recently, gradual receding from the offshore side has been observed in some *Eisenia bicyclis* beds off the coast of southern Sanriku Coast (Taniguchi, 1996). Because reduction of kelp beds directly affect the harvest of economically high-valued inshore resources in this coast, particularly *Strongylocentrotus nudus* and *Haliotis discus hannai* which feed on seaweeds as their main food sources, the degeneration of *E. bicyclis* beds has significant consequences to both the ecosystem and the local fishing community dependent on these resources. In this paper, in order to explore the changes and their causes in *E. bicyclis* beds on the rocky coast in Tomarihama, the Oshika Peninsula in Miyagi Prefecture (northeastern part of Honshu, Japan) was selected as the monitoring site and an ecological survey was conducted on *E. bicyclis* and the major herbivores *S. nudus* and *H. discus hannai*. Using

the data,, the relationship between the extent of the coverage of the *E. bicyclis* bed and the occurrence and density of the grazing species was examined (Muraoka, 2008).

Materials and Methods

The rocky coastal area in Tomarihama on the Oshika Peninsula, Miyagi Prefecture (northern Japan) was set up as the monitoring site (Fig. 3). At the start of the survey, the *E. bicyclis* bed was distributed in the depth range of 2–5m. *Sargassum yezoense* beds were also seen at a depth around 2m. From 5 to 10m in depth, crustose coralline algae were dominated.

In 1999, dan buoys were set at the starting point (0m; inside of the *E. bicyclis* bed) and the terminal point (150m; inside the coralline flats) on the bottom of the sea (Fig. 3). From 1999 through 2001, a 150-m long measuring rope (fixed line) was connected between 0m point and 150m point and used for each investigation. The following survey was conducted:

E. bicyclis Ecological Survey

In August 1999, July 2000, and February, May and July 2001, SCUBA diving surveys were conducted and the number and location of all *E. bicyclis* juveniles (< one year old without dichotomous branching) and adult (> one year old with dichotomous branching) sporophytes growing within 1 m width (i.e. 0.5m either side) of the 150m-long fixed line. Juvenile and adult sporophytes were distinguished using the method of Taniguchi and Kato (1984). At the same time, arm length (the length between top of stipe and base of frond) of all *E. bicyclis* individuals was measured, and the age was estimated using the method developed by Taniguchi and Kato (1984).

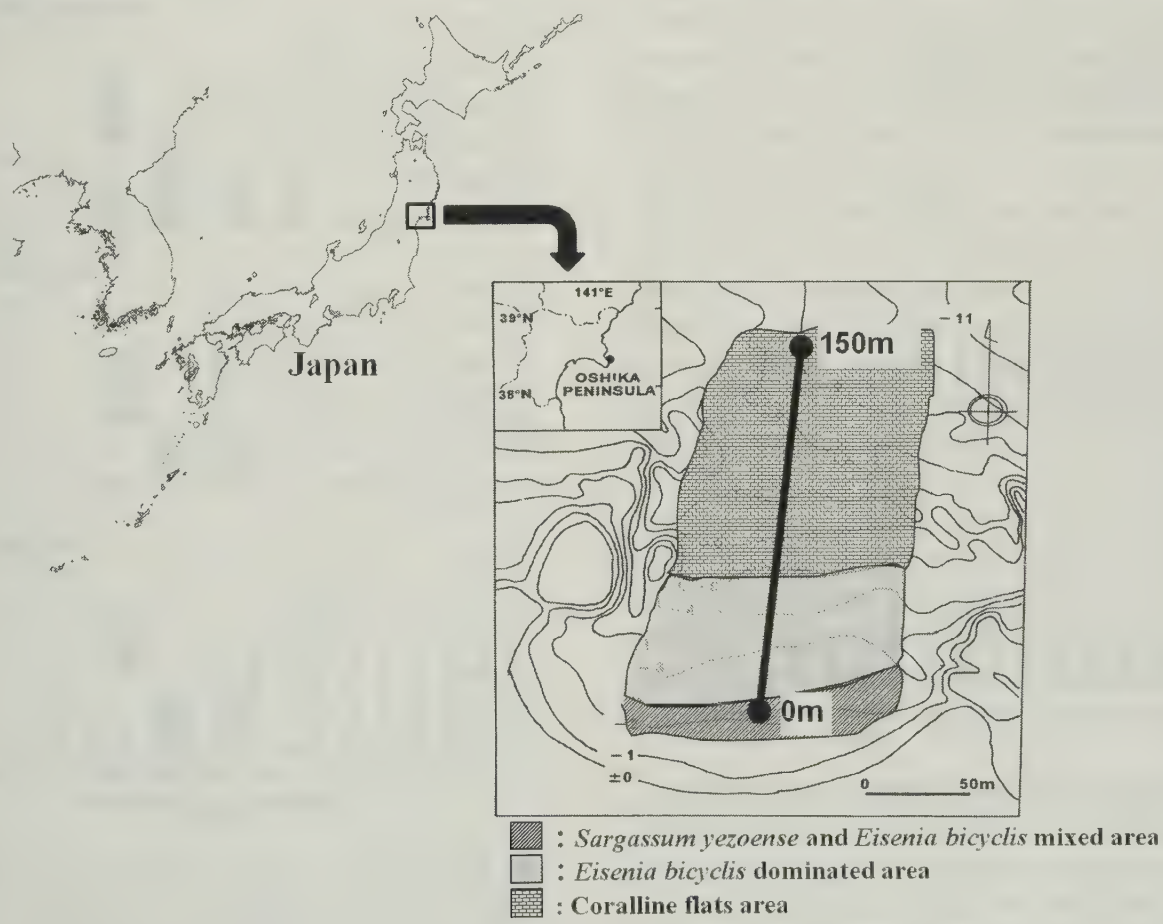

Fig. 3. The survey area and location of the fixed line at Tomarihama, Miyagi Prefecture.

Ecological Survey of *S. nudus* and *H. discus hannai*

In October of 1999, 2000 and 2001, all *S. nudus* and *H. discus hannai*, which were observed within the 1m-width of the 150m-long fixed line, were collected by SCUBA diving. They were carried up from the bottom of the sea to the boat. On the boat, every *S. nudus* and *H. discus hannai* was recorded on its location using the fixed line to pinpoint their exact location and the test diameter was also recorded. Furthermore, in the October 2001 survey, the total weight of *S. nudus* and *H. discus hannai* were measured at intervals of 10m on the fixed line. After measurement, all of *S. nudus* and *H. discus hannai* was returned to the places where they were originally taken from.

Results

E. bicyclis Ecological Survey

Figure 4 shows the distribution of the density of *E. bicyclis* individuals (juvenile and adult sporophytes) at an interval of 10 m along the line for each survey, and the lower limit of *E. bicyclis* adult sporophytes. The densities of adult *E. bicyclis* in the bed ranged 1.08 (July 2000) to 1.80 (February 2001) individuals /m^2. At the start of the survey (August, 1999), the *E. bicyclis* bed extended to 64m on the fixed line. Although the lower limit of adult sporophytes receded to 61m in July 2000, however the settlement of the juvenile sporophytes could be seen up to 80m. However, the juvenile sporophytes that settled at 60-80m had all disappeared by February of 2001; the lower limit of adult sporophytes was 53m in the May 2001 survey. In the July 2001 survey, the settlement of a large number of juvenile sporophytes (283 individuals) was observed at 0-60m on the fixed line. Yet, no settlement could be confirmed at 60-80m. Also, only a few isolated macrophytes could be observed in areas deeper than the lower limit of *E. bicyclis* bed, thus forming a coralline flat.

S. nudus and *H. discus hannai* Ecological Survey

Fig. 5 shows the density distribution of *S. nudus* and *H. discus hannai* in October of 1999, 2000 and 2001. The two species at the survey site, *S. nudus* accounted for 91.1% (1999), 97.3% (2000) and 96.8% (2001) of the total number of individuals, revealing that the major herbivore in the survey area was *S. nudus*. The total number of *S. nudus* was different from year to year, 448 individuals in 1999, 829 individuals in 2000 and 1400 individuals in 2001. Moreover, in terms of the distribution on

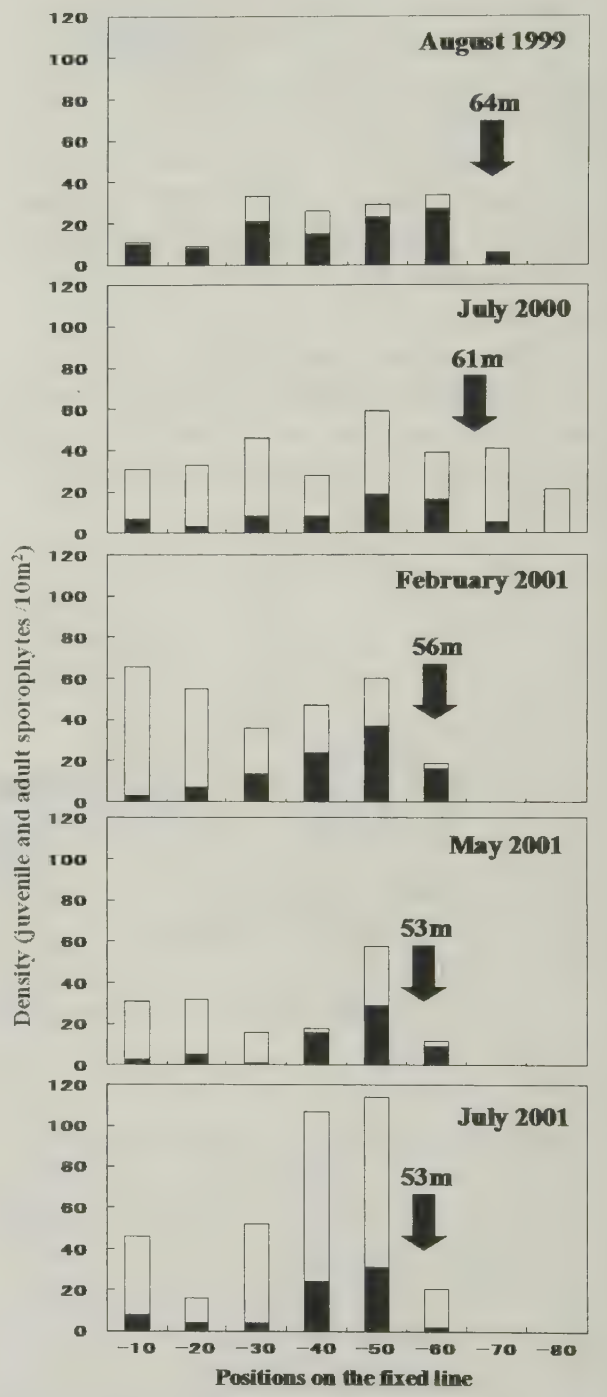

Fig. 4. Density of *E. bicyclis* sporophytes (■ :adult, □ : juvenile) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line (in Tomarihama), ; the arrows denote the position of lower limit of *E. bicyclis* adult sporophytes

the fixed line, the distribution of the two species differed between years, with the boundary around the 50-60m site, which was the lower limit of the *E. bicyclis* bed. For this reason, whereas *H. discus hannai* were distributed at a relatively high frequency on the shallow side (inside the *E. bicyclis* bed), most of *S. nudus* were found on the deeper side (within the coralline flat; Fig. 5). For example, the density of *S. nudus* inside the *E. bicyclis* bed was 3.5 individuals /m^2 in October 2001. On the other hand, the density inside the coralline flat was 12.9 individuals /m^2.

As a result of surveying the test diameter of *S. nudus*, it was found that, although there was dispersion in the number of individuals by survey year, a large number of small individuals with <4cm test diameter were inhabited the coralline flat that spread in areas deeper than *E. bicyclis* bed (Fig. 6). In October 2001, a relatively larger number of *S. nudus* individuals were observed within the *E. bicyclis* bed. Also, 86.7% of the individuals within the *E. bicyclis* bed were large individuals with 4cm or larger test diameter. On the other hand, in the coralline flat, 66.9% of *S. nudus* individuals were less than 4cm in test diameter.

In the 2001 weight measurement, the total weight of *S. nudus* corresponded to 95.6% of the total weight of two herbivores (Fig. 7). For *S. nudus*, the

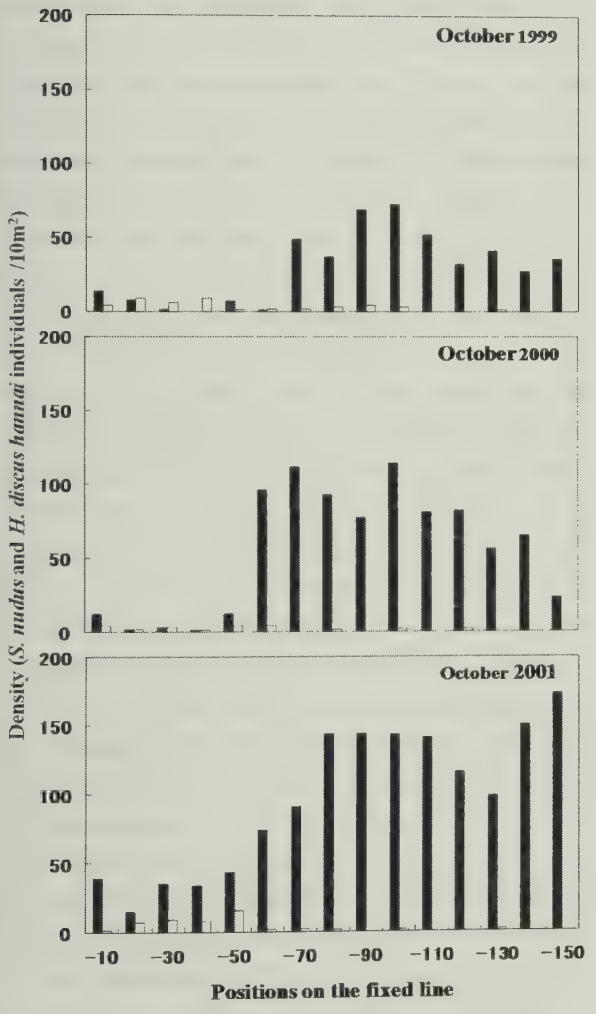

Fig. 5. Density of individuals of *S. nudus* (■)and *H. discus hannai* (□)recorded at an interval of 10 m within a 1m-width of the 150m-long fixed line (in Tomarihama)

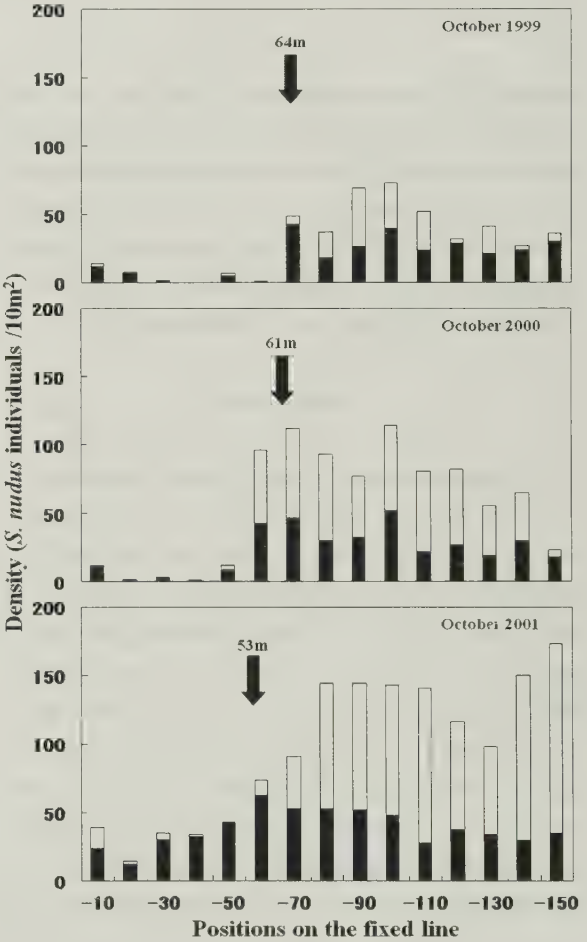

Fig. 6. Density of individuals of *S. nudus* (■ : ≥4cm in diameter; □ : <4cm in diameter) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line (in Tomarihama); the arrows denote the positions of lower limit of *E. bicyclis* adult sporophytes in each year

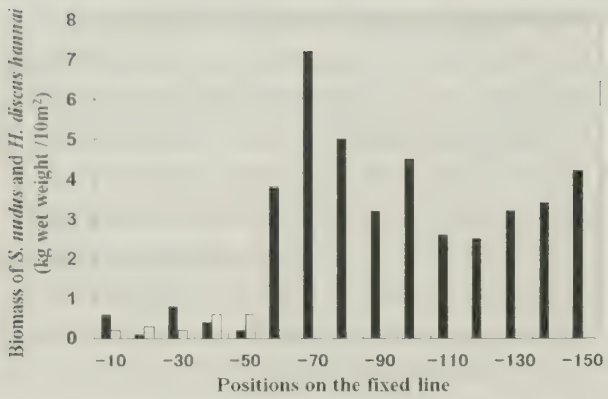

Fig. 7. Biomass of *S. nudus* (■) and *H. discus hannai* (□) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line in October 2001 (in Tomarihama)

biomass of *S. nudus* inside the E. bicyclis bed was 0.06kg /m^2, while the biomass on the coralline flat was 0.40kg /m^2. From the weight measurement survey of *S. nudus* conducted on the line in October of 2001, the biomass obtained from 60-70m site on the fixed rope was 7.2kg, the maximum value, which was followed by 5.0kg, at the 70–80m site (Fig. 7).

Discussion

Sebens (1985) indicated that colonies of erect algae could be changed into coralline flat by grazing of sea urchins. The survey in this study revealed that in the two years from August, 1999 through July, 2001, the lower limit of the *E. bicyclis* bed (adult sporophytes) had receded 11m towards the shoreline (Fig. 4). There is also data that, as of 1981 in Tomarihama, the *E. bicyclis* bed exist from shore to 8m in depth (Taniguchi *et al.*, 1987). 8m depth in the test area is situated at approximately 120m along the fixed line. If this is the case, the bed has retreated approximately 67m in 20 years. The disappearance of kelp (including *E. bicyclis*) beds has been shown to occur because after the existing individuals die of old age, disappear during storms and/or are grazed, the recruitment of the next generation of individuals does not occur for some reason (Kawamata, 1998). The reason could be that there was no supply of spores from the parent seaweed in the first place or for some other reason; i.e., the juvenile sporophytes that had been generated did not survive to become adult. Thus, it became clear that the cause of the receding of the lower limit of the *E. bicyclis* bed in the monitored area was because the juvenile sporophytes do not survive to become adult. This is supported by the fact that the growth of the *E. bicyclis* juvenile sporophytes at the 60-80m site, observed in July of 2000, completely disappeared by February 2001 (Fig. 4). *S. nudus*, the major herbivore in the area occurred mainly from the lower limit of the *E. bicyclis* bed to the coralline flat. Kawamata (1998) suggested that the sweeping action of kelp fronds in turbulent flow was an effective mechanism to deter urchin invasion. It might be one of the reasons why most *S. nudus* were not found inside the *E. bicyclis* bed but on the coralline flat. The results of the weight measurement, at 60–80m where the juvenile sporophytes of *E. bicyclis* had disappeared, showed the maximum biomass (Fig. 7). Based on these findings, it can be inferred that the receding of the lower limit of the *E. bicyclis* bed in the test sea area has occurred in the following way: after the *E. bicyclis* adult sporophytes growing near the lower limit of the *E. bicyclis* bed individuals died of old age, disappeared during storms and/or were grazed, the settled juvenile sporophytes of *E. bicyclis*, which typically would mature as adult, were consumed by the high grazing pressure of *S. nudus* and thus they did not survive to become adult sporophytes. Agatsuma *et al.*, (1997) removed sea urchins from a coralline flat on the Hokkaido coast of the Sea of Japan and confirmed that seaweeds would colonize there if the urchin grazing pressure was removed. Vega *et al.*, (2005) reported that an abrupt change in the spatial-temporal patterns of abundance of the black sea urchin *Tetrapygus niger*, the most conspicuous benthic grazer in northern Chile, produced local extinctions and compression of bathymetric distribution of *Macrocystis integrifolia* and *Lessonia trabeculata* (Laminariales, Phaeophyceae). On the seaward face of Port Erin (Isle of Man, U. K.) large algae on the breakwater do not occur on the lowest 3m. The density of sea urchin *Echinus esculentus* was high, but after removal of the sea urchin, a kelp *Laminaria hyperborea* and other

algae occurred in the lower area (Jones and Kain, 1967). In California, after the mass mortality due to disease of a localized population of a sea urchin *Strongylocentrotus franciscanus*, the formation of kelp forest was followed by the rapid seaward expansion of 4 species of brown algae (Pearse and Hines, 1979). These reports show that the grazing pressure of sea urchins directly affects the colonization of kelp beds.

Most of *S. nudus* inhabiting on the coralline flats were small individuals, while large individuals were dominant within the *E. bicyclis* bed. This finding is consistent with the behavioral pattern of *S. nudus*, which is believed to settle onto a coralline flat area due to the effect of the settlement inducer dibromomethane (Taniguchi *et al.*, 1994), and then move into kelp beds in order to find food to grow (Agatsuma and Kawai, 1997; Sano *et al.*, 1998).

In this area, observations were further continued after 2001, but the expansion of *E. bicyclis* beds has not been verified. Therefore, in order to understand the mechanism of *E. bicyclis* bed fluctuations more clearly, longer-term observations (including oceanographic events) are necessary.

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Restoration of kelp beds on an urchin barren : Removal of sea urchins by citizen divers in southwestern Hokkaido

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Abstract: Along the southwestern coast of Hokkaido, urchin barren dominated by a sea urchin *Strongylocentrotus nudus* and nongeniculate coralline algae has persisted for a long time (locally > 80 years) while kelp beds comprised of *Saccharina japonica* var. *religiosa* and *Undaria pinnatifida* has been restricted in shallow waters largely less than 2 m in depth. Although previous studies have revealed that *S. nudus* is the causative grazer of the barren state by removal of and/or defense from the sea urchin, no practical efforts have been done for the improvement of fisheries ground. As the fishermen on the coast are aged and depopulated, the authors introduced citizen volunteer divers (CVD) for the removal of the sea urchin. The attempt was practiced on an urchin barren near Kamoenai Fishing Port on the southern coast of Shakotan Peninsula in September 2005. Twenty CVD (including a few instructors and staffs) removed sea urchins from two blocks (50 x 50 m, 4-8m in depth) during two dives (ca. 1 hr/dive) beside the control block; subsequent monthly removal by monitors (i.e., researchers) was done in one of the two blocks. In May 2006, the average standing crops of the seaweed (largely kelp) were 865g/m^2 (monthly removed after the CVD activity) and 150g/m^2 (removed once by CVD) but 0g/m^2 in control, while the density of sea urchin were 0.1, 3.5 and 4.2/m^2, respectively. The results show that the introduction of CVD can aid the restoration of kelp beds.

Key words: grazing, *Saccharina japonica* var. *religiosa*, sea urchins, *Strongylocentrotus nudus*, kelp beds, monitoring, removal

Introduction

Urchin barren is a well known non-productive state on the shallow rocky coasts in the world. Southwestern coast of Hokkaido contains the largest urchin barrens in the Sea of Japan coast (Fujita 1998), introduced not only in the domestic (Fujita *et al.*, 2008) but also the foreign review (e. g., Harrold & Pearse 1987). Along the southwestern coast of Hokkaido, urchin barren dominated by a sea urchin *Strongylocentrotus nudus* and nongeniculate coralline algae has persisted for a long time (locally > 80 years, Fujita 1998) while kelp beds comprised of *Saccharina japonica* var. *religiosa* and *Undaria pinnatifida* has been restricted in shallow waters largely less than 2 m in depth. Although previous studies (Agatsuma, *et al.*, 1997, Kawai *et al.*, 2002) have revealed that *S. nudus* is the causative grazer of the barren state by removal of and/or defense from the sea urchin, no practical efforts have been done for the improvement of fisheries ground. As the fishermen on the coast are aged

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and depopulated, the authors introduced citizen volunteer divers (CVD) for the removal of the sea urchin among various methods (e.g., removal by diver, catching using box glasses and the fishing gear from the side of a boat, and catching using trap cages, see Fisheries Agency 2007). On the rocky coast where the topography of the seabed is complex, the removal by divers is considered to be the most efficient method. Employment of professional divers is not economical due to their expensive wages, but recent increase of amateur divers encouraged us to use them because some of them are searching for the opportunity to use their skill of diving for contribution to the society. In this paper, we report on the first trial of removal of sea urchins in an urchin barren Kamoenai Village to suggest their potential for the restoration of seaweed beds.

Materials and Methods

Location of the study site

The study site is located near Kamoenai Fishing Port on the southwestern coast of Hokkaido, facing to the Sea of Japan (Fig. 1). Because of high density of sea urchins, kelp beds are restricted to onshore rocks shallower than 2 m in depth. Three 50m × 50m square blocks (A, B and C) were framed using ropes on urchin barren boulder beds at depths between 4 and 8m. The CVD removed sea urchins from the blocks A and B in September 2005. After that, in the block A, monitors (i.e., researchers) removed sea urchins once a month. Block C is a control where no sea urchins were removed.

The method of sea urchin removal

Removal of sea urchins by CVD was carried out in September 23 and 24, 2005. Ten CVD (six men and four women) participated in the removal. Including the instructors and staffs, a total of 20 divers were separated into 2 teams and each 10 divers treated one of two blocks (A and B). They spent 1 hr/day for two days. Their goal was the perfect removal of the sea urchin in blocks A and B. Removed sea urchins were transplanted to an artificial fish shelter deployed in shallower waters where non-kelp algae were abundant (Fig. 1).

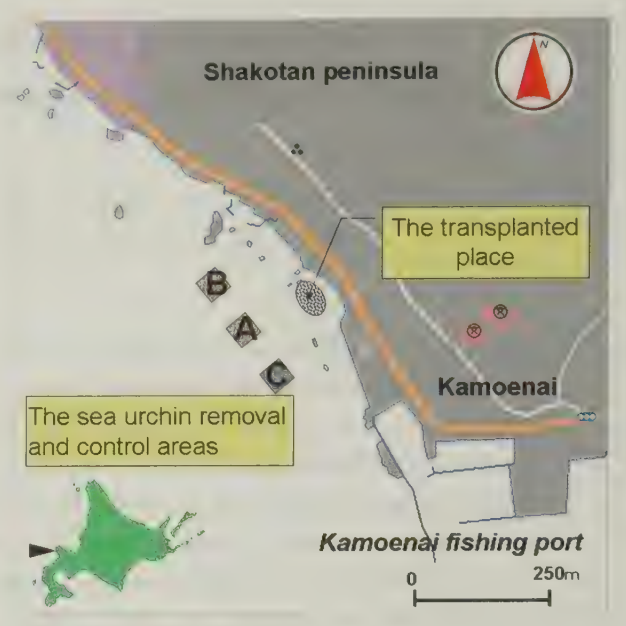

Fig. 1. Location of sea urchin removal experiment site A (removal each month, n=4), B (removal once, n=1), C (control) and the transplanted place to which sea urchins were transplanted from A and B areas.

Fig. 2. The view on the sea bottom *S. nudus* and coralline algae

Fig. 3. Sea urchin removal by a citizen diver

The monitoring investigation

For monitoring after the removal of sea urchins, fixed ropes were used as guidelines which had 10 marks every 5 m at the center of each block. A 1m × 1m quadrate was installed at 10 marked points and the number of sea urchin and the coverage of the seaweed within the quadrates were recorded. 21 quadrates samplings were made in each block. After the removal by CVD, the monitors (i.e., researchers) measured the density of the sea urchin in each block and repeated removal of sea urchins in the block A once a month. In May 27, 2006, the standing crop of seaweed and the number of sea urchin in each area were recorded.

Results

The removal of sea urchin by the citizen divers

The state of the sea bottom of the study site is shown in Fig. 1. It was a typical urchin barren dominated by a sea urchin *S. nudus* and crustose coralline algae (Fig. 2). In addition, *S. intermedius* sparsely occurred. The dominant seaweed distributing in shallower zone is *S. japonica* var. *religiosa*. During the 2 days, sea urchins were removed to the degree that they could not be readily observed and the goal was achieved (Fig.3 and 4). Among the removed sea urchins, 90 urchins were landed for the measurement of test diameter, body weight and gonad weight by the participants. The averages of test diameter, body weight and gonad index (gonad weight/body weight x 100) were 47.6 mm, 44.3 g and 12.2 %, respectively. These were small sea urchins with unmarketable immature gonads. The total wet weights of the removed sea urchins were 710.6 kg in the block A and 746.5 kg in the block B. A total of 32,900 sea urchins (1,645 urchins per person) were removed during the two days.

Results of the monitoring investigation

The change of the sea urchin density of each block is shown in Fig. 5. In the control block C, sea urchin density varied from 4 to 5 per 1 m^2, but in the block B (removed only once by CVD in Sept.), the sea urchin density was approximately half of that in the block C. In the block A where sea urchins were monthly removed, the density could be reduced to almost less than 1/ m^2. In the observation in February 20, 2006, the seaweed had not germinated yet but diatoms and small green algae formed a mat on the hard substrata. In May 27, 2006, the average

Fig. 4. The participating citizen divers and staff

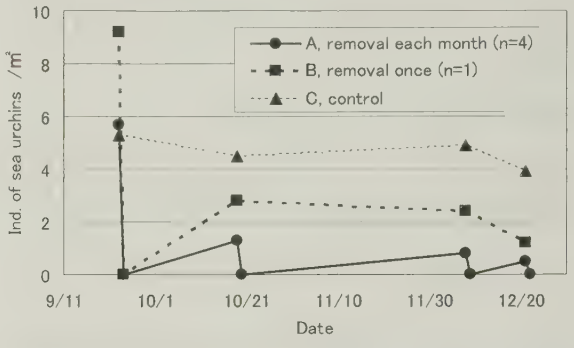

Fig. 5. The change of the sea urchin density of each area

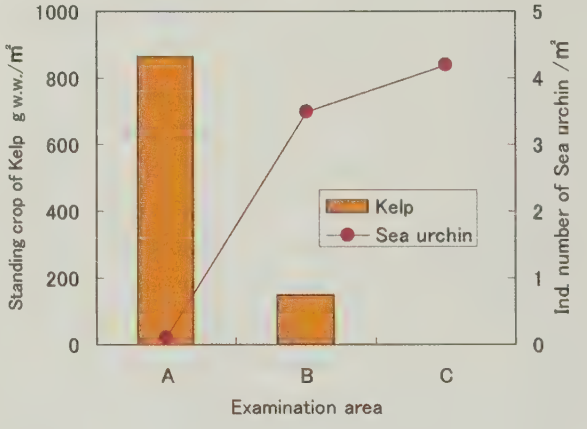

Fig. 6. Results of the monitoring in May, 2006. A (removal each month, n=4), B (removal once, n=1), C (control)

Fig. 7. The state of the early stages and the sea bottom after sea urchin removal

of standing crop of the kelp in each block and the number of the sea urchin are shown in Fig. 6. The standing crop of the kelp in the blocks A, B and C were 865g/m^2, 150g/m^2 and 0g/m^2, while the density of sea urchins were 0.1, 3.5 and 4.2 /m^2, respectively. The results show that CVD can contribute more or less to the restoration of kelp beds on urchin barrens by the removal of the sea urchin (Fig. 7).

Problems and perspective of sea urchin removal by citizen volunteer divers

Because CVD has no fishing rights, they need the agreement of the fisheries cooperative and the permission from the prefectural government to remove sea urchins because of strict limitation by the prefectural fishery adjustment rule. Furthermore, CVD may be mistaken as poachers if not well informed among the related offices. Therefore, further understanding and permission should be need for CVD to support their diving activities on management of seaweed beds. Even a temporal and local introduction of CVD can bring the success in restoration of kelp beds in an appropriate time of the year. In the southwestern coast of Hokkaido, the timing should be autumn, namely usually before inactivation of *S. nudus* in cold winter and in and before the maturation of kelp *S. japonica* var. *religiosa*. To enlarge the activity, introduction of CVD not only compensates the lack of fishermen divers, but activates fishing villages by promoting human exchanges and information. Further monitoring is needed to establish the management of the restored kelp beds (e.g. frequency of the subsequent removal, the best way to enlarge the restored kelp beds), Infrastructure for divers in port area as well as new educational system and services are also needed to enlarge these activities to the other parts of the coasts.

Conclusion

In this report, we introduced a possibility of restoration of kelp beds by removal of sea urchins by citizen volunteer divers. The sea urchin *S. nudus* was again confirmed to be the causative grazer to disturb, re-colonization of kelp. This should be a breakthrough which coincided with the central dogma of Isoyake Taisaku Guideline (2007), referring to the priority of reduction of limiting factors in colonization of seaweeds, and should be replaced of deployment of concrete blocks or rubble stone beds, which provide habitats of sea urchins. We hope this trial will be the first step of collaboration between fishermen, citizens and researchers in the restoration of kelp beds on urchin barren.

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The authors thank several fishermen from Kamoenaimura Fisheries Cooperative for their help in this investigation.

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Biological aspects of herbivorous fishes in the coastal areas of western Japan

Atsuko YAMAGUCHI[*1]

Abstract: Seaweed beds in Japanese coastal waters have significantly declined in recent years, and feeding by herbivorous fish has been identified as one of the potential causes of this decline. In the western coastal areas of Kyushu, seaweed consumption by fish species such as the mottled spinefoot, *Siganus fuscescens*, sea chubs, *Kyphosus* spp, and the Japanese parrotfish, *Calotomus japonicus*, has become a matter of concern. Our study group has been investigating the biological aspects of herbivorous fish in the coastal waters around western Kyushu and Okinawa. In this paper, I introduce some of the results of my work focusing on the biology of herbivorous fish, including their distribution, feeding, and behavioral ecology. Investigation of the stomach contents of herbivorous fish revealed that *K. bigibbus* fed mainly on *Sargassum* throughout the year. In contrast, other fish supplemented their diet of seaweed with amphipods and other organisms. Experiments to determine food preference were performed on captive *K. bigibbus*, and their results supported the results of the stomach-content analysis. Both experiments showed that the fish selectively fed on *Sargassum fusiforme* and *Undaria pinnatifida*. Herbivorous fish off the west coast of Kyushu were tracked using a biotelemetry method. The fish inhabited seaweed beds during the daytime. The activity of *S. fuscescens* and *K. bigibbus* markedly declined when the water temperature decreased to approximately 20℃ and 17℃ respectively. It was observed that these fish overwintered in these areas. This study demonstrates that the recent rise in winter ocean temperatures has extended the period of activity of herbivorous fish. The results contradict the hypothesis that herbivorous fish species migrate northward during warm periods.

Introduction

Seaweed beds in Japanese coastal waters have significantly declined in recent years, and feeding by herbivorous fish has been identified as one of the potential causes of this decline. The recent increase the temperature due to global warming is considered to have led to the northward extension of the distribution of herbivorous fish species in western Japanese coastal waters. Moreover, it has been proposed that the change in the distribution of fish populations has lead to an increase in seaweed consumption by these species. However, detailed information on the biology of herbivorous fish has not been obtained. The cause and effect relationships between feeding damage inflicted by herbivorous fish and "Isoyake" have not yet been elucidated. Seaweed biomass in western Japanese coastal waters is considered to have decreased, and it appears that the balance between herbivorous fish populations and seaweeds has been temporarily disturbed.

In the western coastal areas of Kyushu, the increase in seaweed consumption by fish species such as the mottled spinefoot, *Siganus fuscescens*, sea chubs, *Kyphosus* spp., and the Japanese parrotfish, *Calotomus japonicus*, has become a matter of concern (Kiyomoto, 2000; Kiriyama *et al.*, 2005a, 2005b; Fig. 1).

Our research group have been studying the

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distributions, feeding habits, reproductive behavior, growth, migration, population structure, and other biological aspects of herbivorous fishes in coastal waters, including those around western Kyushu and Okinawa (Fig. 2).

Our findings show that *Kyphosus* spp. are very important to understand the feeding damage inflicted on seaweed beds by herbivorous fish. *Kyphosus* species have not been widely studied because they are not very important from the perspective of fishery. In Japan, 4 species belonging to the genus *Kyphosus* are found (Sakai and Nakabo 2004), and all of them are distributed in western coastal Kyushu. *K. pacificus* is a more tropical species, and we usually found it in Okinawa. The most abundant *Kyphosus* species is *K. bigibbus*, which occupies the waters off the coast of Nagasaki, western Kyushu. It is relatively large *Kyphosus* species.

Since the catches of these fish decrease as the water temperature decreases, it was unclear why extensive damage due to feeding by fishes is detected in autumn and winter.

Behavior and migration

In this study, I have attempted to answer the following questions. Do herbivorous fishes migrate from tropical areas? What is their migration range? Do they migrate to seaweed beds for feeding?

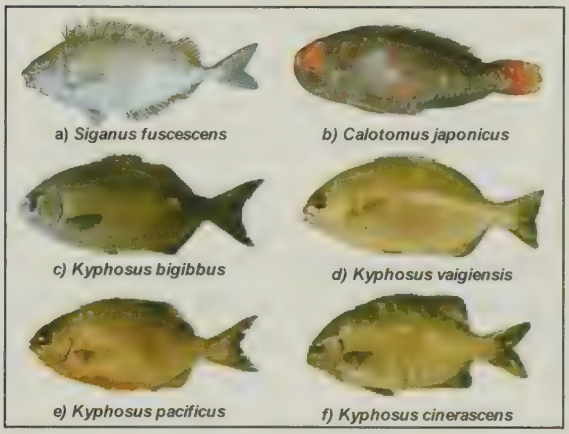


Fig. 1. Main target herbivorous fish species investigated in our study.

Fig. 2. Main coastal areas investigated in this study

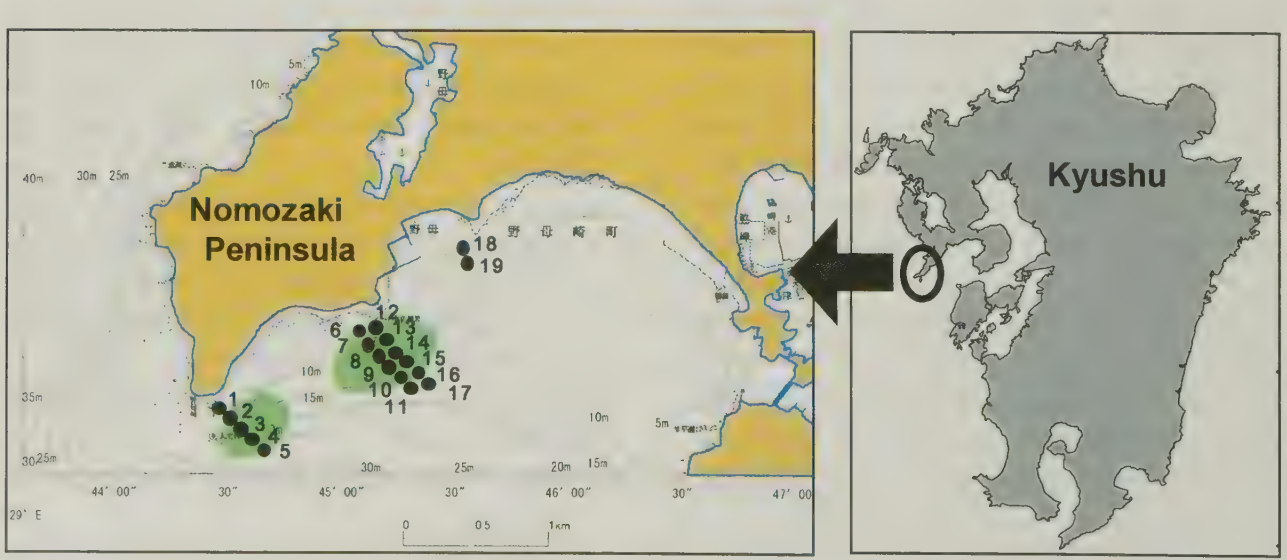


Fig. 3. Study sites in Nomozaki, Nagasaki. The circles and numbers denote the positions of the receivers.

Where do they migrate to during winter? The behavior and migration of the fish were evaluated using ultrasonic telemetry methods (Yamaguchi *et al.*, 2006). Fish were caught using set nets and kept alive for several days. Their dorsal fins were then tagged, and the fish were released. Ultrasonically tagged fish were detected using fixed VR2 monitoring receivers (VEMCO). Transmitter signals were randomly generated at intervals of 45 – 75 seconds; this intermittent signal generation extended the battery life to approximately 150days. Preliminary investigations were conducted to determine the detection range. In our study sites, the receivers accurately detected signals from the transmitters when the former were placed within a distance of 80 m from the latter. Prior to passive tracking of the fish, we tracked the moving range of both *S. fuscescens* and *K. bigibbus* in real time by using some specimens of the 2 species. On the basis of these results and the ecological information previously acquired by our study group, I placed 19 receivers mainly on the seaweed bed in Nagasaki (Fig. 3). A total of 93 individuals (*S. fuscescens*, n = 76; *K. bigibbus*, n = 11; *K. vaigiensis*, n = 5; and *C. japonica*, n = 1) have been tracked since the first examination in November 2004 (Fig. 4).

Fig. 4. *Kyphosus bigibbus* with transmitter attached (a) and VR2 receiver (b).

Figure 5 shows the moving ranges estimated using the total number of signals detected by each receiver in 2007 For *S. fuscescens*, most signals were received from the transmitters placed in seaweed beds at Kotate(nos. 6 – 17). Few signals were detected from the seaweed beds in Ootate (nos. 1 – 5). Further, the migration range of *K. bigibbus* was larger than that of *S. fuscescens*.

The typical daily movement patterns in autumn of *S. fuscescens* and *K. bigibbus* have been studied (Yamaguchi *et al.*, 2006). The mottled spinefoot (*S. fuscescens*) did not move at night and stayed close to the receivers placed in deep areas. It began to swim after the sunrise and actively swam in the seaweed areas during the day. After the sunset, it probably returned to the same place close to the receivers in the deep areas and did not move again until the sunrise. In contrast, in the case of *K. bigibbus*, no signals were detected from the seaweed beds in the nighttime. However, it was clear that the fish returned to the seaweed beds in the daytime via a fixed route. It appeared that at sunrise, *K. bigibbus*

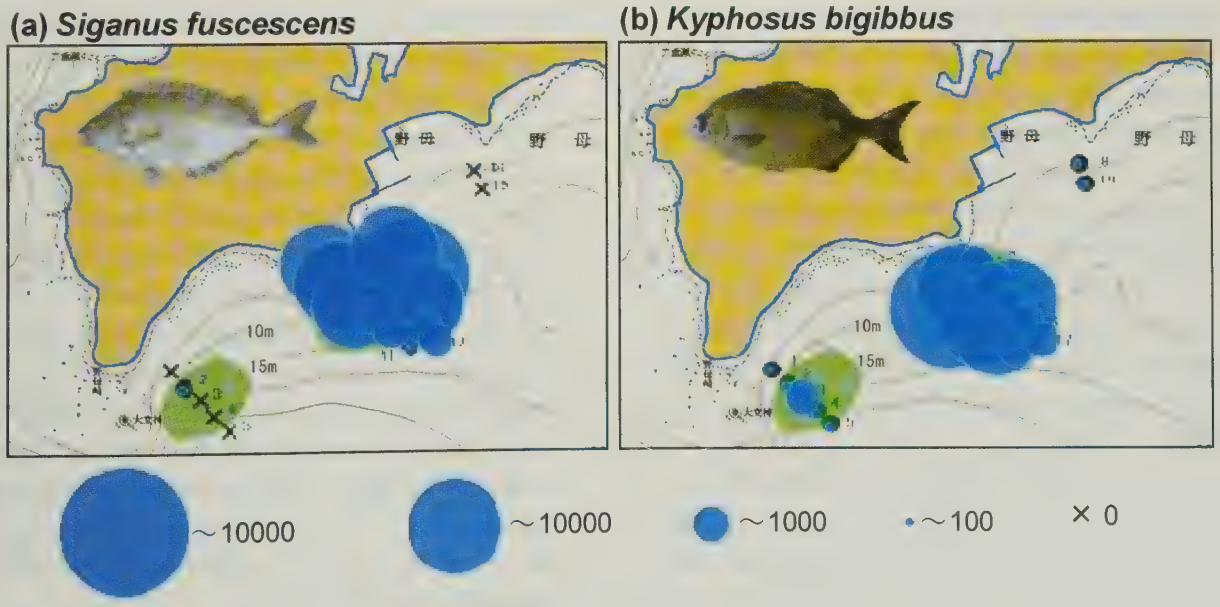


Fig. 5. Total number of signals recorded by each receiver in 2007.

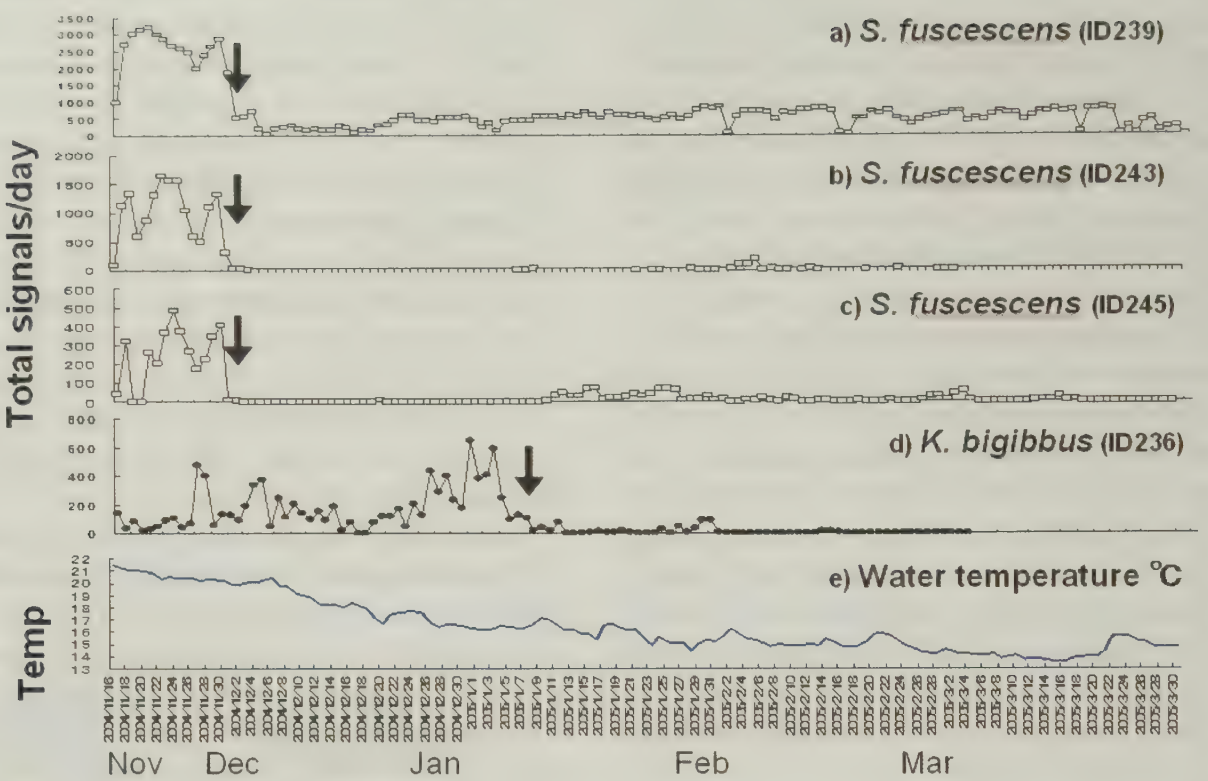


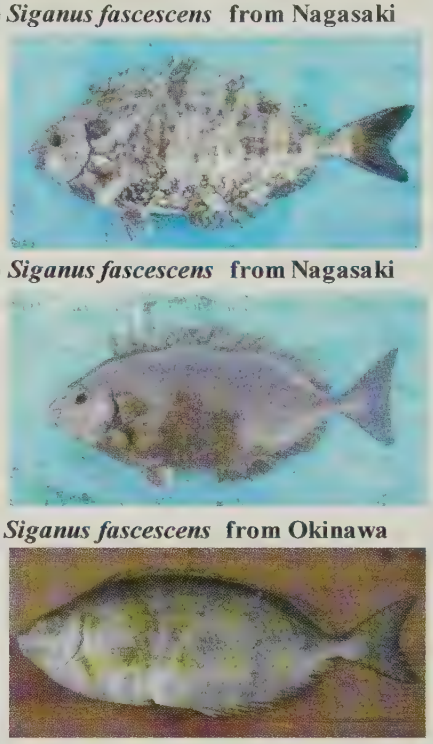
Fig. 6. Total number of signals recorded per day from November 16, 2004 to March 30, 2005 for 4 specimens (a – d) and changes in water temperature in the study area off Nomozaki at a depth of 7 m (e).

approached the seaweed beds from the western side of the peninsula after traveling a relatively long distance. Then, it turned out that a fish returns to the west side of peninsular again after the sunset. The west side is a reef zone; I estimate that *K. bigibbus* inhabits this zone during the night.

However, these typical patterns changed when the water temperature decreased. Although both species inhabited the seaweed beds between December and January, they seemed to be moving slowly. Even though the habitat had not changed much, the home ranges of the fish seemed to be relatively deeper in winter. Figure 6 shows the relationships between the total number of signals per day for *S. fuscescens* and *K. bigibbus*, and the water temperature from November 2004 to March 2005 (Yamaguchi *et al.*, 2006).

As shown in the figure, the number of signals from all *S. fuscescens* individuals markedly decreased from the beginning of December when the water temperature was 20℃. In the case of *K. bigibbus*, the number of signals decreased from the second week of January, when the water temperature was 16 – 17℃. It was found that the activity of both species decreased as the water temperature fell. It is generally regarded that these herbivorous species migrate to southern areas during winter; however, in this study, signals continued to be transmitted from the study sites during winter. This finding indicates that the fish overwinter in same places and that they do not migrate. Further, the decreased activity of these fish species is probably why fish catches decrease during winter. These results, therefore, contradict the hypothesis that herbivorous fishes migrate southward during winter. The water temperature in the coastal areas of western Japan has tended to be high since the mid 90s (Yamaguchi *et al.*, 2006), and has increased by approximately 1 – 2℃. Thus, our research demonstrated that the rise in recent winter ocean temperatures has extended the period of activity of herbivorous fishes by at least 2 months. This may be the cause of the severe damage to seaweeds.

Fig. 7. Japanese parrotfish, *Calotomus japonicus*, swimming in a tank. Herbivorous fishes were kept in captivity in order to study their feeding habits such as selective feeding.



Three mottled spinefoots from Nakasaki (a, b) and Okinawa (c). The morphological characteristics such as white dot patterns and body depth are quite different.

Food preference

It is unclear if herbivorous fishes consume seaweed, and if they do, it should be determined whether they consume seaweed selectively or non-selectively. In our research group, experiments to determine food preferences are performed on captive adult and juvenile individuals of *Kyphosus* species and *C. japonicus* that are kept in tanks (Fig. 7). Investigation of the stomach contents of herbivorous fish revealed that *K. bigibbus* fed mainly on *Sargassum* throughout the year. Therefore, *K. bigibbus* specialized for feeding on seaweeds. In contrast, other fish supplemented their diet of seaweed with amphipods and other organisms. The main food consumed by *S. fuscescens* was also seaweed; it remained in 85% of all, and other organisms, such as skeleton shrimps, were found. Compared with *K. bigibbus* and *S. fuscescens*, *K. vaigiensis* showed a considerably varied diet. *K. vaigiensis* mainly consumes crustaceans such as skeleton shrimps and seems to be omnivorous rather than herbivorous. In the coastal areas of Kyushu, feeding damage to *Ecklonia kurome* was found, even though these 3 species consumed only small quantities of the seaweed. In fact, only *K. bigibbus* specifically consumed sea algae. *E. kurome* is an important species in the seaweed beds in Kyushu. In our study, *E. kurome* was rarely found in the stomachs of herbivorous fishes, even though it is severely damaged by some fish species in natural environments (Kiriyama *et al.*, 2001). Therefore, the preference captive of herbivorous fishes for 5 species of brown algae was studied using multiple-choice feeding experiments. In the case of *K. bigibbus*, the results of the above experiment supported the results of the stomach-content analysis and showed that *K. bigibbus* selectively fed on *Sargassum fusiforme* and *Undaria pinnatifida*. *E. kurome* was the least preferred by *K. bigibbus*. During winter, the biomass of *S. fusiforme* and *U. pinnatifida* is low; therefore, it is probable that during winter, *K. bigibbus* consumes *E. kurome*. Similar experiments are currently being conducted on other fish species.

Population structure of *S. fuscescens*

Our research group studied the morphometric variations in and the mitochondrial genetic structure of *S. fuscescens* and determined whether or not

several populations of *S. fuscescens* exist.

Here, I will focus on the morphological differences between 2 geographic populations of *S. fuscescens* from Nagasaki and Okinawa. The morphological characteristics of the fishes, such as white dot patterns and body depth, were quite different as shown in Fig. 8.

To determine whether locality could be determined solely on the basis of morphometric characteristics, a quadratic discriminant analysis was carried out. The analysis yielded 95% correct assignment of specimens to the locality. The Okinawa population appeared to significantly differ from the Nagasaki population.

The results of genetic studies revealed the significant differences between two populations. Also, they suggested that the Japanese populations were genetically different from Southeast Asian population (Yagishita and Yamaguchi, unpublished data). Therefore, the number of individuals of *S. fuscescens* that migrate from tropical areas such as Okinawa does not appear to be large enough to explain the damage cause to seaweed beds around Japan.

Conclusion

In conclusion, I emphasize the 2 following points: (1) Our results regarding behavior and migration contradicted the hypothesis that herbivorous fish species migrate southward during winter. These fish do not migrate over such a long distance. Further, the results of population genetic studies indicated that the migration of *S. fuscescens* from Okinawa is insufficient to explain the damage caused to seaweed beds around Kyushu. (2) The water temperature in western coastal Japan has tended to be high since the mid 90s. In autumn and winter, especially, the water temperature increases by approximately 1－2 ℃. Thus, our research demonstrates that the recent rise in winter water temperatures has extended the period of activity of herbivorous fish by at least 2 months. In winter, the seaweed biomass is relatively low, but the activities of these fish remain high. This may explain the severe damage to seaweed. Moreover, seaweed biomass seems to have decreased, and it appears that the balance between herbivorous fish populations and seaweed has been temporarily disturbed.

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Inhibitory effects of wave action on destructive grazing by sea urchins : a review

Shigeru KAWAMATA [*1]

Abstract: Wave-induced water motion is one of the key determinant factors protecting kelp assemblages from destructive grazing by sea urchins; however few studies have quantitatively evaluated the hydrodynamic effect on rocky subtidal community ecology due to the complex nature of the water motion. Our quantitative understanding of the effects of waves on urchin foraging behavior has increased substantially over the past 15 years, primarily due to flow tank experiments on the sea urchin *Strongylocentrotus nudus*, which have formed extensive urchin barrens in northern Japan. This review evaluates the mechanism and extent that the oscillatory water flow influences the behaviors of sea urchins. The dislodgement velocity for stationary sea urchins, which has been determined in various studies based on the hydrodynamic theory, is discussed. Previously predicted dislodgement velocities for sea urchins are extremely high (> ca. 5 m/s) while the velocity limit for urchin movement on a smooth and flat substratum is much lower than 1 m/s. The importance of attachment by spines to urchin movement in moving water is discussed. Dense cover of turf algae prevents the effective attachment of the distal suckers of tube feet and thus substantially reduces the critical velocity for urchin movement. Urchin climbing of upright thin objects, such as anchor ropes of buoyed systems for kelp cultivation, to which little attention has been paid, is discussed in relation to oscillatory water motion. Finally, the effect of oscillatory flow on urchin feeding is discussed.

Key words: barrens, grazing, kelp, sea urchin, waves

Introduction

Kelp beds have a fundamental role in maintaining populations of various fish and invertebrates by providing food and habitats (Tegner and Dayton. 2000; Edgar *et al.*, 2004). Many kelp species are both highly productive (Mann, 1982) and have a high nutritive value for various herbivorous animals many of which are of considerable economic importance, in particular abalone and sea urchins (Uki, 1981; Uki *et al.*, 1986; Nabata *et al.*, 1999; Scheibling and Anthony, 2001) However, sea urchins often are extremely abundant and denude the substratum of erect macroalgae, forming extensive 'urchin barrens', and this phenomenon has been recorded worldwide (Harrold and Pearse, 1987; Scheibling *et al.*, 1999). Urchin barrens generally have low productivity (Mathieson *et al.*, 1991) and are persistent.

In northern Japan, sea urchins, such as *Strongylocentrotus nudus* and *S. intermedius*, also dominate significant areas of subtidal rocky bottom and have formed extensive urchin barrens, limiting the colonization of kelp (Nabata *et al.*, 1992; Abe and Tada, 1994; Muraoka, 2008). These urchins are legally protected as fisheries resources exclusively for the commercial fishing by the local fishermen's cooperative. Nevertheless, few urchins are harvested in barrens due to their poor growth and low quality of the edible gonad, allowing the maintenance of urchin barrens. Many attempts including sea urchin removal and the placement of physical barriers (Kawamata, 2001a), have been made for

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kelp restoration but most of them have failed, partly because of the high mobility of sea urchins.

The wave-induced oscillatory water motion, which increases with decreasing depth, is one of the most important factors controlling urchin grazing. Sea urchins undoubtedly have the ability to move on any type of substrata, including rock overhangs, rugged mussel beds, algal turf areas, plastic netting fences and upright thin ropes, by maneuvering their tube feet and spines. However, sea urchins are rare in wave-exposed shallow areas, allowing macroalgae to survive and grow, with the presence of abundant urchins in the adjacent barrens. Such a distributional pattern of kelp beds and urchin barrens is common in the temperate zone. In rocky subtidal areas on the northeastern Pacific coast of Honshu, the main island of Japan, the sea urchin *Strongylocentrotus nudus*, forms extensive and persistent urchin barrens, but wave-exposed shallow reefs are generally dominated by kelp such as *Eisenia bicyclis*. Although many ecologists have described the importance of wave action in the rocky subtidal community structure, few studies have quantitatively assessed it, partly because wave-induced water motion is highly variable over time and complex. In principle, however, wave-induced water motion can be measured and predicted by engineering techniques, and thus quantitative assessment will provide useful insights into not only the spatial distributions of urchins and algae but also practical methods for kelp restoration.

Our quantitative understanding of the effects of waves on urchin behavior has increased substantially over the past 15 years, primarily due to flow-tank studies. I have used two different flow tanks for urchin-behavioral studies. The first an oscillating flow tank, which is a U-shaped pipe with a piston, reproducing wave-induced oscillatory flows. In addition, a circuit flume tank which can reproduce standing waves with a reversible impeller. In this review, I discuss the hydrodynamic effects on urchin behaviors in relation to attachment, movement and feeding.

Attachment

The ability of a benthic organism to withstand strong water motion depends on its attachment strength relative to the hydrodynamic forces. Sea urchins apparently achieve greatest attachment strength by the use of both their spines and tube feet for bracing and adhesion in shelter holes or crevices. During foraging outside of shelters, the use of spines in bracing is necessarily reduced, thus making the tube feet the primary mechanism of attachment (Lissner, 1983; Kawamata, 1998). A stationary organism in unsteady, oscillatory water motion experiences the acceleration force in addition to the forces (i.e., drag and lift) caused by instantaneous water velocity (Denny, 1988). At intertidal sites, the acceleration force imposed on a stationary organism is significant because the water acceleration can be extremely high, over 100 m s^{-2} (Denny, 1985; Gaylord, 1999). At subtidal

Table 1. Dislodgement velocity for sea urchins

Species	Dislodgement velocity (m/s)	Reference
Echinometra mathaei	6.3 [1)]	Denny and Gaylord (1996)
Strongylocentrotus purpuratus	15.4 [1)]	Denny and Gaylord (1996)
S. droebachiensis	5.0 [1)]	Siddon and Witman (2003)
Arbacia lixula	5.5 [2)]	Santos and Flammang (2007)
Sphaerechinus granularis	4.6 [2)]	Santos and Flammang (2007)
Paracentrotus lividus	8.2 [2)], 6.1–7.0 [3)]	Santos and Flammang (2007)

[1)] Prediction at which 50% urchins will be dislodged.
[2)] Prediction for the maximum attachment force which an urchin should achieve by attaching with all their adoral tube feet.
[3)] Prediction for attachment forces measured in the field.

sites, however, the acceleration force is virtually negligible, because when wave-induced orbital velocity reaches a maximum, water acceleration becomes zero, and because the wave-induced water acceleration is much lower than the gravitational acceleration of 9.81 m s^{-2} (Barber, 1969; Kawamata, 2001b). Thus, an estimate of the dislodgement velocity, defined as the critical velocity at which an organism will be dislodged, is obtained as the velocity at which the velocity-induced force becomes equal to the attachment strength. Dislodgement velocities predicted in this manner for urchin species are summarized in Table 1.

The wave-induced water velocity in subtidal areas is limited by water depth. The maximum water velocity, U_{max}, caused by waves in shallow water is

$$U_{max} = 0.3\sqrt{g(H+d)} \qquad (1)$$

where g is the acceleration due to gravity (= 9.81 m s^2), H the wave height, and d the water depth (Denny, 1988). The wave height increases with decreasing depth but is limited due to the wave breaking. Although the ratio of the wave height to depth at breaking varies in a complex relation with the bottom slope and the steepness of waves,

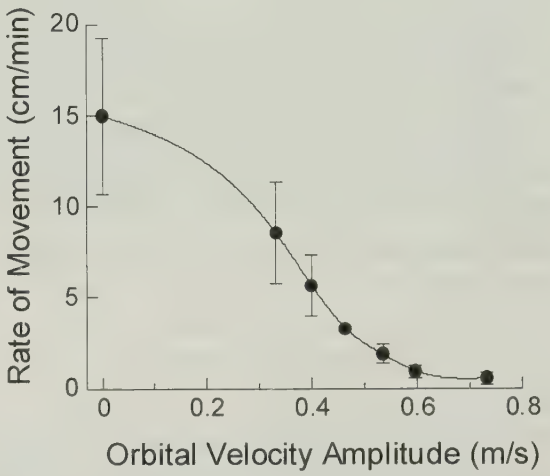

Fig. 1. Maximum rate of movement of *Strongylocentrotus nudus* in oscillatory flow (Kawamata, 1998).

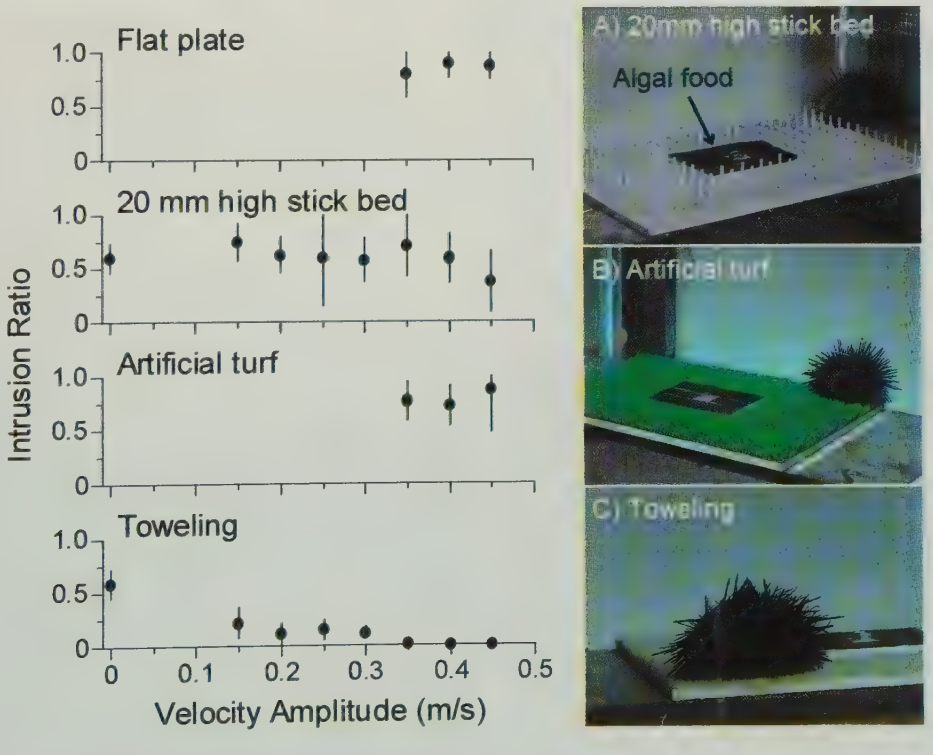

Fig. 2. Intrusion ratios of *Strongylocentrotus nudus* for the control flat plate and experimental substrata in different velocity amplitudes (Kawamata and Furuhata, unpublished data). Error bars indicate 95 % confidence intervals.

possible ratios are limited to as high as 1.4 for steep slopes (Denny, 1988). Thus, the maximum possible water velocity is

$$U_{max} = 0.46 \sqrt{g\,d} \qquad (2)$$

It is predicted from Eq. 2 that the dislodgement velocity of sea urchins is very unlikely to occur in subtidal areas. For example, when d = 4 m, U_{max} is only 2.9 m/s. Taking into account the additional attachment strength due to bracing of spines, the distributional area of sea urchins generally cannot be limited by the wave-induced dislodgement while being stationary.

Benthic movement

During movement, urchins are much more subject to the effects of water motion than when attached while being stationary. Fig. 1 shows the maximum rate of movement by *Strongylocentrotus nudus*, which was stimulated with a spot light in oscillatory flows. The urchins showed minimal ability to move at about 0.7 m/s. Attachment to the substratum by tube feet is a primary factor affecting the mobility of sea urchins. This was found by the oscillating-flow-tank experiment (Kawamata and Furuhata, unpublished data) which tested the inhibitory effects on sea urchin invasion over several types of substrata, including a stick bed, artificial turf and toweling (Fig. 2A, B and C). Contrary to initial speculation, only toweling had a clear effect on urchin invasion, as shown in Fig. 2. The ordinate represents the intrusion ratio, defined as the ratio of the number of the 'intrusion successes' (mounting a test substratum entirely) to that of the 'intrusion trials' (contact with the edge of the substratum). The intrusion ratio remained as high for the stick bed and for the artificial turf as for the control flat plate at a velocity amplitude of 0.35 m/s. In contrast, the ratio was significantly lower for toweling than for the stick bed even at as low as 0.15 m/s. The mechanism for toweling to inhibit urchin invasion is very simple. Tube feet attach to the substratum with their distal suckers. On toweling, however, the suckers fail to achieve an effective attachment to the fabric texture of the toweling, so that urchins cannot easily move in moving water.

A good example of such substratum effect in nature is the colonization of barren substratum by rapid-growing turf algae prior to the formation of kelp *Laminaria religiosa* stands on the Sea of Japan coast of Hokkaido, northern Japan. The kelp generally dominates the wave-exposed shallow area from mid winter to early summer, while after summer *Strongylocentrotus nudus* denude the substratum of erect macroalgae up to the upper limit of the subtidal area forming extensive barrens. In the absence of non-crustose algae, sea urchins forage even to the uppermost part of the subtidal zone exposed to surging waves (Fig. 3A). When an algal carpet is formed, however, then sea urchins are excluded from the area, even at calm sea conditions (Fig. 3B).

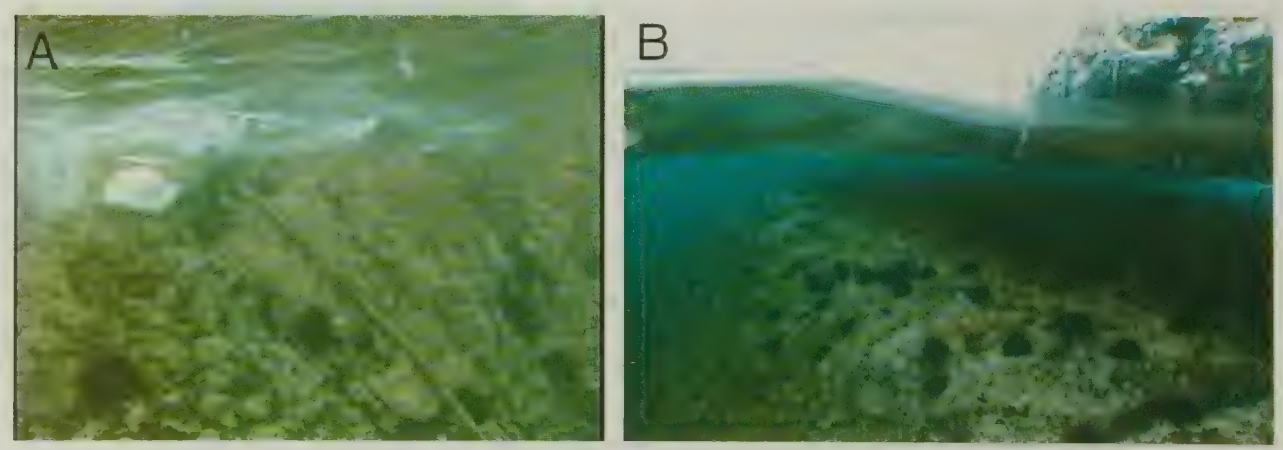

Fig. 3. The uppermost part of the subtidal on the Sea of Japan coast of Hokkaido immediately before (A; 27 December 1999) and after early colonization of algae (B; 4 January 2000) (Kawamata, 2001a).

Vertical movement

Little was known about vertical movement in sea urchins, and line cultivation methods have been used in urchin barrens without much consideration for the climbing ability of sea urchins. Actually, however, sea urchins climb even thin vertical ropes as long as food is limited on the seabed (Fig. 4). A recent laboratory study (Kawamata, 2008) showed the high climbing performance of *Strongylocentrotus nudus* in oscillatory flows using upright rods of 10 and 3 mm diameters with algal food items attached at 2.5 cm intervals. In this case, sea urchins climbed the rods to graze on food items from the bottom one by one although they did not always reach the top food item. In the absence of oscillatory flows, urchins readily climbed and grazed on almost all the food items even for thin rods. Urchin climbing was reduced in height and in frequency as the velocity amplitude increased. However, the animals were able to climb even at 0.4 m/s regardless of the rod diameter.

A flume tank experiment was also conducted on the climbing performance of *S. nudus* for swingable and fixed columns covered by microalgae in oscillatory flow (Fig. 5). Contrary to initial speculation, sea urchins also climbed the swaying upright objects if food was un available elsewhere.

Feeding

Feeding is even more susceptible to water motion than movement because the mechanical instability of sea urchins increases during feeding as follows. Sea urchins have their mouth at the center of their attachment base so that they must detach more than half the number of their tube feet used to cling to the substratum while feeding. At the same time, the animals must overcome the additional drag on algae. Therefore, the upper velocity limit for feeding on foliose macroalgae is lower than that for movement (Kawamata, 1998). Oscillating-flow-tank studies (Kawamata, 1998; 2001a) indicated that the velocity limit for feeding may somewhat vary with animal size and algal morphology but is limited to less than ca. 0.4 m/s.

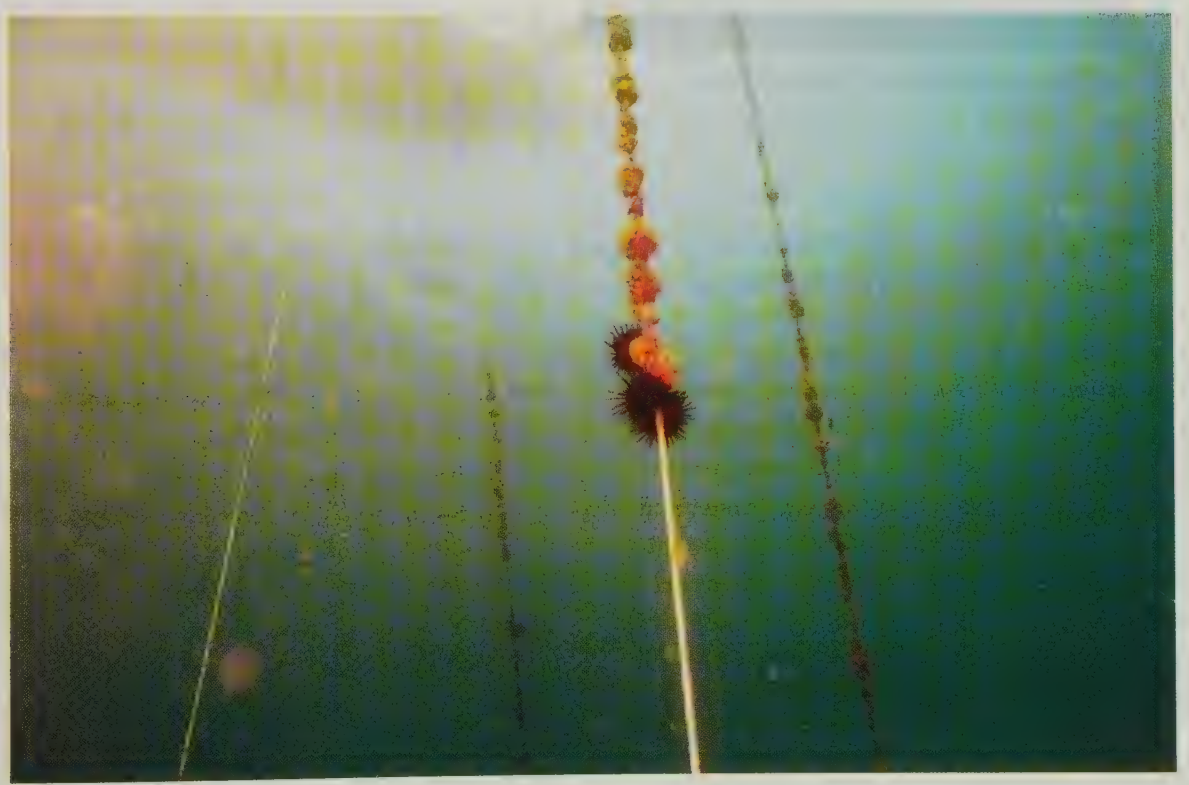

Fig. 4. Sea urchins (*Strongylocentrotus nudus*) climbing anchor ropes to feed on algae in an urchin barren of Miyagi, Prefecture northeastern Pacific coast of Honshu.

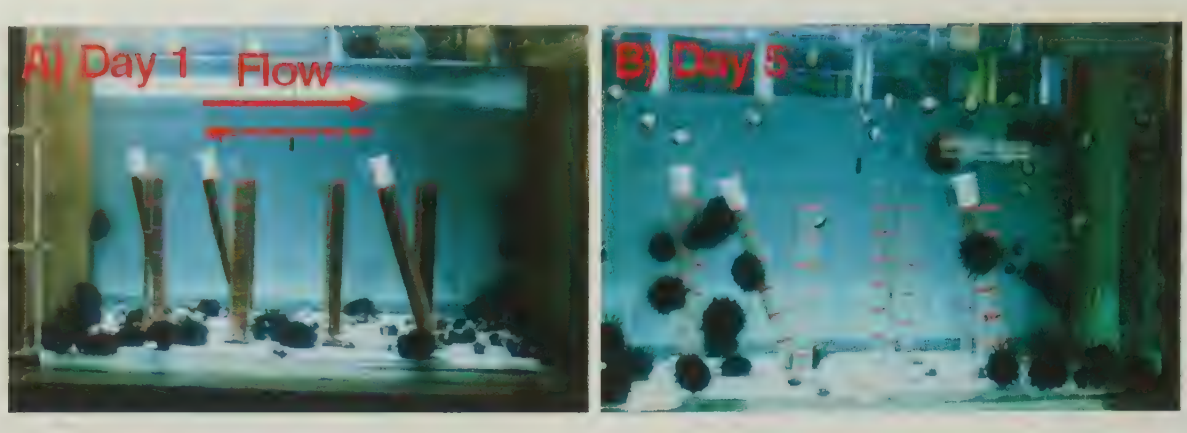

Fig. 5. Sea urchins (*Strongylocentrotus nudus*) climbing on swingable as well as fixed rods in the oscillatory flow with the velocity amplitude of 0.15 m/s (Kawamata unpublished data). The microalgae had initially covered the entire surface of both kinds of rods (A) and then were almost completely grazed by climbing urchins on day 5 (B).

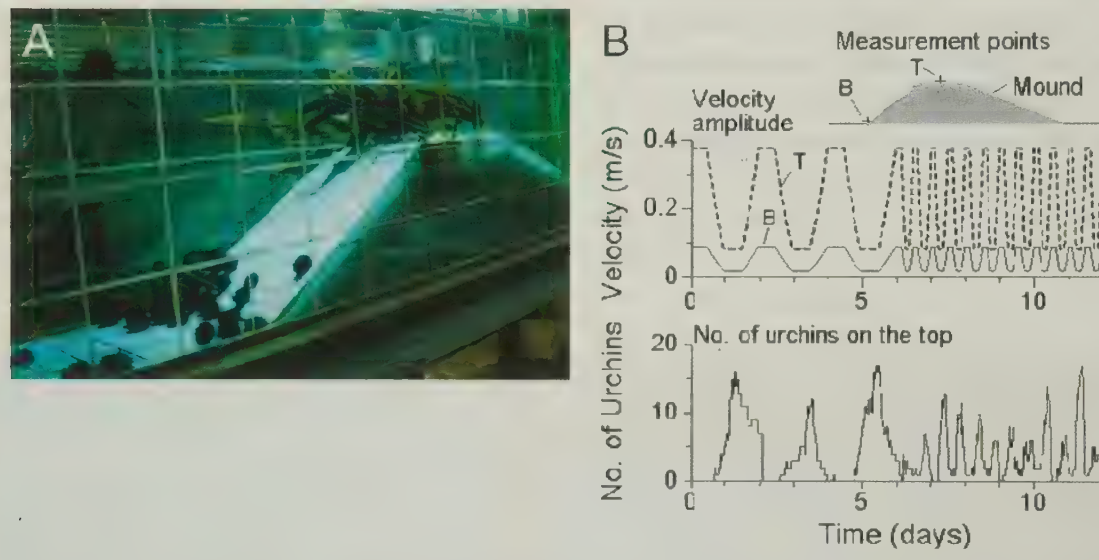

Fig. 6. A flume tank experiment on the foraging behavior of the sea urchin *Strongylocentrotus nudus* in the vicinity of a *Laminaria* bed placed on the top of a mound (Kawamata, 2001a).

In addition, the wave-induced movement of macroalgal fronds, called the "whiplash" effect, may repel urchins away from macroalgal stands. Although many studies described the importance of the whiplash effect in the survival of algal stands in dense urchin barrens (e.g. Velimirov and Griffiths, 1979; Himmelman, 1984; Dayton, 1985; Konar, 2000; Gagnon *et al.*, 2003; Konar and Estes, 2003), few studies have quantitatively assessed the water motion which cause the movement of algal fronds (Kawamata, 1998; 2001a; Gagnon *et al.*, 2006). Kawamata (2001a) conducted a flume tank experiment on the behaviors of *S. nudus* around a *Laminaria* bed placed on the mound under waves (Fig. 6). In the experiment, strong and weak wave periods were repeated over a 12 day period in the pattern shown in Fig. 6. The velocity amplitude at the top of the mound where kelp plants were placed was higher than that at the bottom of the mound. The movement of the urchins up and down the slope in response to the change in water velocity was clear from the results aggregated at the edge of the kelp stands as the water motion decreased. On the contrary, they began to move back away from the stands when the velocity amplitude increased beyond only 0.1 m/s.

Conclusion

Foraging activity of sea urchins is greatly affected by wave action through limiting movement and feeding rather than through dislodgement. The effects of waves on urchin behaviors can be quantitatively understood by laboratory flow-tank experiments, while wave-induced water motion is too complex to readily assess in nature. Such quantitative information coupled with the assessment of water motion will provide insights not only into urchin-kelp interactions but also into useful methods for kelp restoration in urchin barrens.

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Reducing overgrazing by sea urchins by market development

Tsutomu MIYATA [*1]

Abstract: Overgrazing by sea urchins has turned algal beds barren on many coasts of Japan. When sea urchins are removed, the algal beds recover. However, There are problems with the importation of cheaper sea urchins from overseas and labor shortage work against the removal of sea urchins by domestic fishermen. On the other hand, a local market for the excess sea urchins could be developed to expand consumption. Problems remain in increasing the catch of the sea urchins and selling them rapidly, but fishermen producers could increase both the catch and markets gradually.

Key words: economic approach, imports, local production for local consumption, sea urchin, urchin barren

Introduction

The world's main sea urchin producing countries are Chile, Japan, the United States, Russia, China (mainly by culture), and Canada (FAO-Production, 2000-2006). The main exporting countries are Chile, Canada, the United States, and Korea (FAO-Commodities, 2000-2006). Japan is the largest importer and consumer of sea urchins (FAO-Commodities, 2000-2006).

In the ecological view points, sea urchins are the important herbivores which determine the structure of seaweed communities. Over populational sea urchins bring about barrens and an increase of worthlessly thin sea urchins after depleting the available seaweeds. Moreover, the denudation by sea urchins resulted in the loss of breeding or nursery beds for fish and shellfish.

The removal of sea urchins allows the seaweed beds to recover, but commercial productivity of sea urchins remains low because fishermen have to improve the thin gonads (roes) when collected from urchin barrens. The situation is ironical: an excess of sea urchins is damaging the fishing grounds so that fishermen expected the decrease of the population, while buyers import sea urchins from overseas. Why the domestic sea urchins cannot be collected and eaten?

This author examined the impediments to commercialize the excess sea urchins and why Japan imports sea urchins. The report describes the development of a new market in Iwate Prefecture that takes advantage of the abundant sea urchins.

Materials and Methods

Data were collected by interviewing to members of fisheries cooperatives in northern Japan, principally Iwate prefecture and at a wholesale market as well as their records and statistics published by the Ministry of Agriculture, Forestry, Ministry of Finance and Hokkaido pref. and by Fish stat Plus (FAO). A case study refered to the report of Miyata (2007).

Why Japan imports sea urchins

From the investigation, three main reasons were extracted to suggest the sustainable imports of sea urchins from all over the world (Table 1).

The first reason is the high price in the domestic market, The price of imported sea urchins (fresh

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Table 1. Values of imports by country
(Unit : us $1000)

	2004	2005	2006
Canada	534	400	288
Japan	218,197	200,402	190,138
Korea	227	166	174
USA	7,388	8,707	7,113

Source : Fishstat Plus (FAO).

or chilled) in Japan was 2.7 times higher than that in the USA in 2006. The high price is due to the high wages in the fishing and processing industries, and the labor-intensive nature of processing sea urchins: breaking shuck, picking out gonads, washing, removing contaminants with tweezers, and displaying the gonads on wooden plates. All of the process need skills not to damage gonads for fear of loss of market value.

Second, Japanese consumers have come to expect yearround availability of sea food though production of domestic sea urchins are limited in summer (Fig. 1). Thus, the industry depends on imports of raw materials out of the season (Fig. 1),

Finally, sea urchins are eaten not only as high-priced sushi and sashimi, but also as canned, bottled, and pouched products, and as low-priced sushi. These lower-priced commodities are made from frozen sea urchins imported mainly from Chile.

Factors preventing use of abundant sea urchins

Interviews to the fishermen also revealed that several factors inhibit the collection of abundant sea urchins on urchin barrens. First, overfishing can exhaust the resource of sea urchins as was in some parts of Hokkaido Pref. the most productive region in Japan. Some fishermen consider that persistence of urchin barrens with thin-gonad sea urchins are better conditions for them than exhaustion of resources.

Second, the target species in Hokkaido are mainly kita-murasakiuni (*Strongylocentrotus. nudus*) and ezo-bafununi (*S. intermedius*), which are sympatric in most habitats Because the latter fetches higher prices, the fisheries cooperatives stock the fishing grounds, in spite of the abundance of the former species, which is more likely to cause urchin barrens. Third, demand: Brand products are in high demand by consumers, but they are not needed in quantity. The distribution of large quantities of a brand reduces the price in the market and alleviates the scarcity, so that some fisheries cooperatives and fishermen hesitate to increase the catch. Therefore,

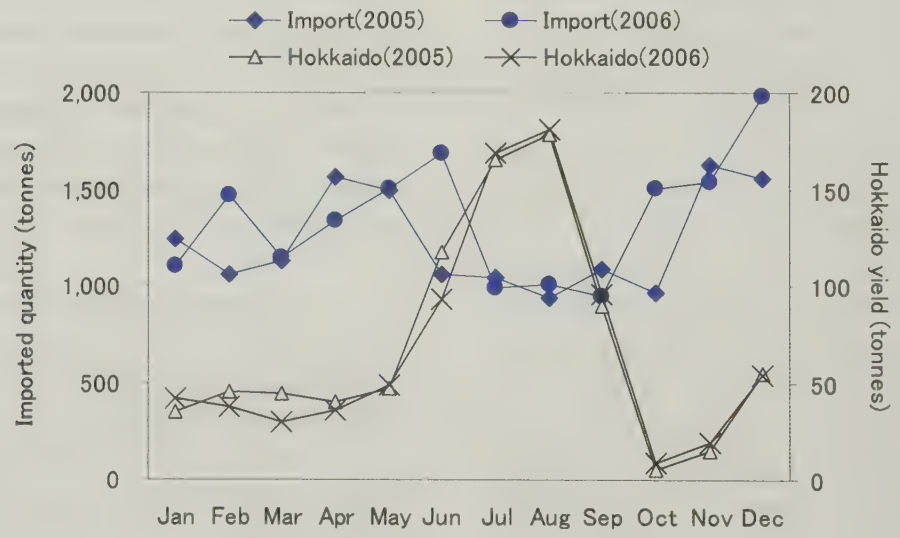

Fig. 1. Monthly imports of live sea urchin and catch in Hokkaido
Import data, live sea urchins only. Hokkaido data, shucked sea urchins.
Source: Trade Statistics of Japan; Hokkaido gyogyou gensei.

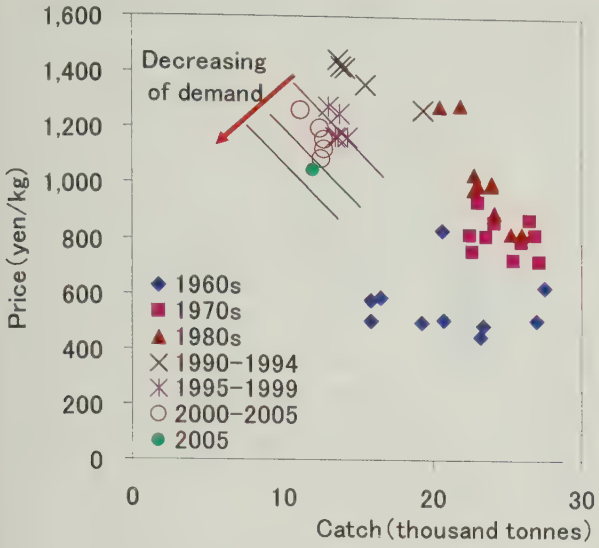

Fig. 2. Trend of demand for sea urchin caught in Japan
Catch data = weight with shell. The price is deflated by consumer price index. Source: Annual statistical report of fisheries and aquaculture production (MAFF)

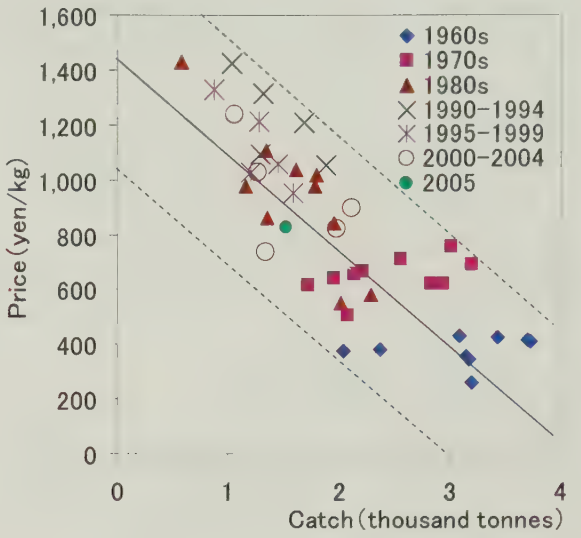

Fig. 3. Trend of demand for sea urchin caught in Iwate pref.
Catch data = weight with shell. The price is deflated by consumer price index. Source: Annual statistical report of fisheries and aquaculture production (MAFF)

maintenance of brand may perpetuate the urchin barren.

Fourth, the decrease of labour; as fishing efforts and labors have reduced, the labor force is insufficient in areas where fishermen process sea urchins by themselves. This decline in labor has allowed sea urchin populations to expand and thus enlarge and maintain urchin barrens.

Finally, after the sea urchins have eaten all the available seaweed and left urchin barrens, they are on the verge of starvation to be of little commercial value. These sea urchins can be reared by supplying kelp, but kelp-habitats are usually quite limited or far from the urchin barrens, so the cost to obtain kelp (transport or culture) is an obstacle.

Case study of successful market development

1. Background

The current demand for domestic sea urchins is at its lowest since the 1970s, owing to competition with imported raw and frozen sea urchins (Fig. 2). The supply of and demand for sea urchins caught in Iwate Prefecture is contrast with those of other domestic sea urchins (Miyata, 2008): the demand for sea urchins caught in Iwate Pref. has hardly changed (Fig. 3). This case study examined the reasons for the competitive ability of sea urchins collected in Iwate Prefectural coasts and the strategy used to maintain the demand.

2. Research site

The research site is Iwate Pref. with a population of 1.4 million (Fig. 4). The rural prefecture is famous for its agriculture and fisheries. The sea urchins caught in Iwate Pref. are sold locally according to thesea urchin processors in Iwate Pref..

Domestic sea urchin production is concentrated in northern Japan: Hokkaido Pref. produces 44% of the catch (mean of 1996 – 2005), Iwate Pref. 11%, Aomori Pref. 7%, and Miyagi Pref. 7%. In southern Japan, only Nagasaki Pref. comes third, at 9% (Table 2).

3. Increased imports favor sea urchins produced in Iwate

People in Iwate Pref. have traditionally eaten fresh roe of sea urchins in summer. They prefer very fresh roe of sea urchins caught on the coasts of Iwate Pref. However, since around 2000, fresh roe of sea urchins have been supplied mainly from Russia

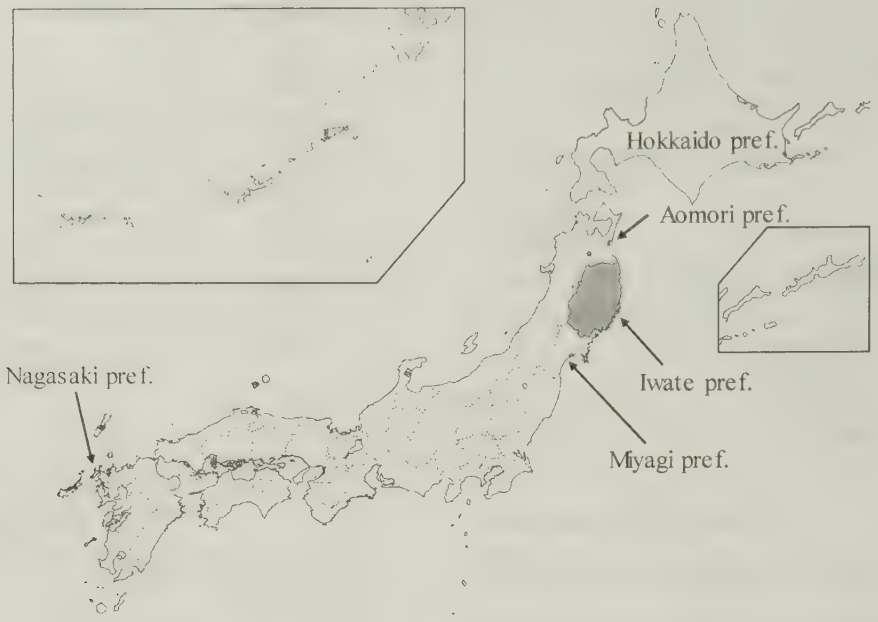

Fig. 4. Iwate Prefecture, Japan.

during autumn to spring (Fig. 1, Fig. 5), and the sea urchin have shifted from a seasonal item to the year-round one. Fast-food sushi and conveyor-belt sushi made of fresh imported sea urchins have formed a new market. Iwate fishermen are worried that local sea urchins will be expelled by imports from Russia.

On the other hand, processors continue to demand for sea urchins caught in Iwate Pref. because of their high ratio of roes, freshness, and a trend of local production for local consumption. Local consumers also prefer local sea urchins for their high quality. Therefore, producers in Iwate Pref. have been able to avoid the decrease of demand for local sea urchins seen elsewhere in Japan.

Sea urchins produced in Iwate Pref. are very fresh because they are processed as soon as they are caught. In contrast, as imported sea urchins are not as fresh as ones caught in Iwate Pref. because of transportation out of water for a few days Sea urchins from Iwate Prefectural coasts have the advantage of freshness.

Table 2. Share of sea urchin yield by district

(Unit : tonnes)

District	Quantity	Percent	Ranking in Japan
Hokkaido	5,664	44%	1
Iwate	1,442	11%	2
Aomori	938	7%	4
Miyagi	920	7%	5
Total	8,964	70%	
Japan	12,816	100%	

Source : Annual statistical report of fisheries and aquaculture (1996-2006) production (MAFF)

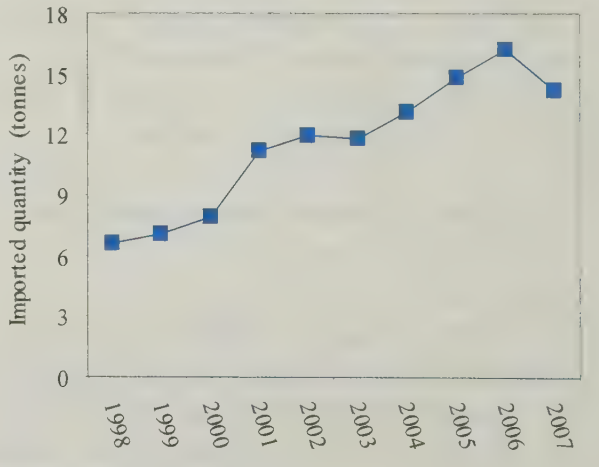

Fig. 5. Imported quantity trend of live sea urchin. Source: Trade statistics of Japan

4. Response to opportunity in Iwate

To meet the demand for local sea urchins and to increase production and sales, a fisheries cooperatives in Hirono Town, Iwate Pref., began stock culture of sea urchins. Stock culture makes it possible to ship sea urchins not only in summer, but in spring and sometimes winter. Maintaining the supply throughout the year thus meets the demand of local consumers to eat local sea urchins. Some processors have indicated their intention to buy stock-cultured sea urchins, so the fisheries cooperatives are planning to shift from the experimental stage to the practical stage. However, it is difficult to make rapid progress in the sock culture of sea urchins for commercialization, so the fisheries cooperative plans to expand gradually. As many fishing villages lack enough labor, the fishermen want fisheries cooperative to develop small-scale stock culture to improve distribution and selling.

Considerations

To resolve the problem of urchin barren, the support of fishers and volunteers of removal of sea urchins, as well as a local governmental subsidy are needed. Important considerations include the high price of sea urchins in Japan, which provides an opportunity for sales of the abundant sea urchins collected from urchin barren if the gonads are improved. This will not be easy, however. Impediments include the aging and depopulation of the fishermen and processors. The low price of year-round imported sea urchins is another problem.

However, local production for local consumption has begun to penetrate the local markets and the development of production and sales strategies will help to reduce the expansion of the urchin barrens. As a result, it will be possible to reduce the costs and labors of controlling the density of sea urchins on urchin barrens.

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Isoyake Studies in Shizuoka Prefecture, Japan

Masatoshi HASEGAWA [*1]

Abstract: A type of isoyake in which *Ecklonia* forest died suddenly has been known in Izu Peninsula in Shizuoka Prefecture since 1911. On the Hainan Coast, the kelp forest which was the biggest in Japan has disappeared by isoyake in Japan. We struggled for the establishment of restoration of kelp and for clarification of the cause of the isoyake of Hainan Coast. The isoyake on Hainan coast was not affected by the high water temperature as was reported in Izu Peninsula of the Shizuoka Prefecture, but was thought as follows. The light condition deteriorated as a background of the isoyake. As a result, the productivity in the *Ecklonia* population was lowered. In addition, browsing by rabbitfish joined as a factor of the persistence of isoyake. By the observation on the alteration of generation in isoyake area in Izu in 2004, it was thought that the browsing of the parrotfish seemed to be a factor of isoyake.

The marine forest which is the biggest in Japan

Hainan Coast, around Cape of Omaezaki in Shizuoka Prefecture is facing to Gulf of Suruga in the east and the Enshunada in the west (Fig. 1). The shoreline is a sandy beach, while the offing is the bedrock. Large brown algae (*Ecklonia cava* and *Eisenia arborea,* Fig. 5) grew thick well on the bedrock, forming the kelp forest. The kelp forest was as large as 8,000 ha, which was reported to be the largest kelp bed in Japan.

Various marine organisms inhabited the kelp

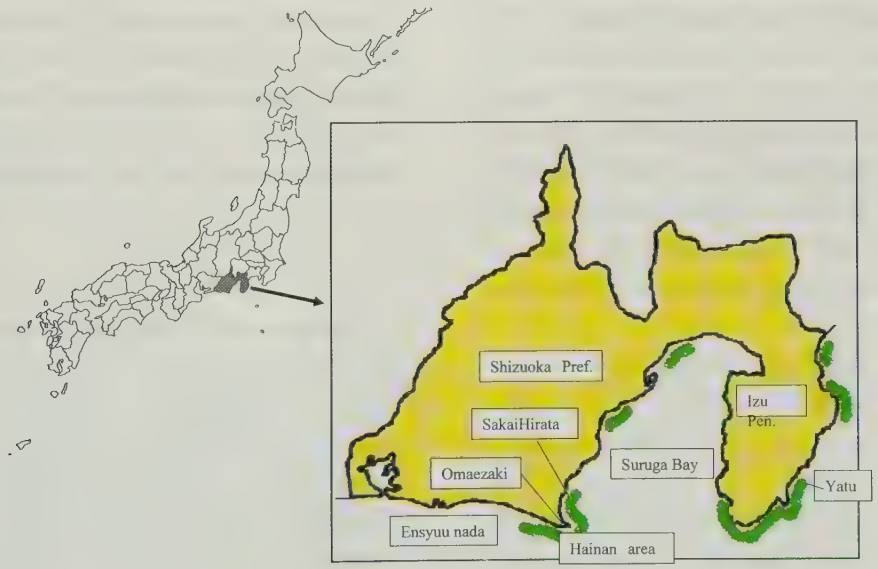

Fig. 1. Map showing Shizuoka Prefecture and its marine forest (green zone)

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forest. Particularly, the forest of *Ecklonia* was a good fishing ground of the abalones. Abalone fishery by the helmet diving apparatus began in the Meiji era (1867-1911). Later the fishermen have continued fishing 10-20 ton of abalone while 100,000-400,000 juveniles have been released (Fig. 2). In addition, the *Eisenia* has been gathered as food for a long time (from perhaps, Nara era).The changes in the harvest of *Eisenia* after 1981 in the Jitougata and the Sakai-Hirata Fishermen's Cooperatives which share most of the harvest in Fig. 2. The catch of around 20-40 ton was in the golden age in both fishermen's cooperatives.

The outbreak of isoyake

On Hainan Coast, isoyake occurred from 1985. *Ecklonia* and *Eisenia* suddenly died and the kelp forest has disappeared afterwards. The isoyake must be the largest in Japan because it was the disappearance of the biggest kelp forest in Japan. That the restoration of *Ecklonia* forest has been partially succeeded, resulting in the establishment of a small forest around the project area since 2005.

Isoyake in *Ecklonia* forests has been known in Izu Peninsula in Shizuoka Prefecture (Fig. 1) since Yendo (1903). However, we have not experienced such a large isoyake as about 8,000 ha before.

According to the monitoring by Izu Branch of Shizuoka Prefectural Fisheries Experiment Stasion, the isoyake of *Eisenia* forests occurred from about 1985 and that in the *Ecklonia* forest from about 1990. As *Eisenia* itself is the commercial species, isoyake directly damaged the fishery (Fig. 2). Furthermore, the catch of abalone which depends on *Eisenia* and *Ecklonia* as food also decreased (Fig. 2) and gave the local fishery production a big blow. The amount of the direct damage was estimated to be about 100-200 million yen (@ 7,000 yen) in abalone fishery and about 40-80 million yen (@ 2,000 yen) in *Eisenia* harvest. Among the damage of isoyake, direct damages in coastal fishery can be calculated as shown above. However, few studies have been done about productivity and the environmental safeguard of the fishing ground through the kelp ecosystem and the indirect damage has been evaluated. Furthermore, the indirect damage of isoyake has not been estimated in quantity. If values of seaweed resources and environment in kelp forests are estimated, the restoration of kelp forest will be promoted not only as the necessity in fishery but as the necessity in society.

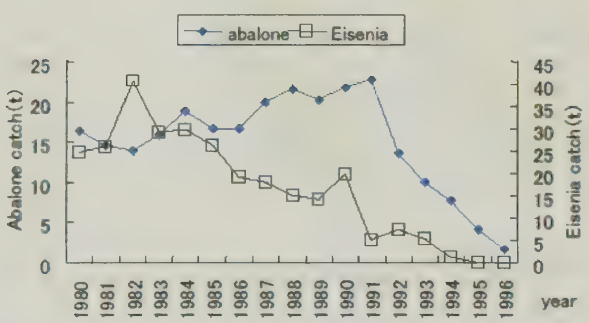

Fig. 2. Catch of abalone and harvest of *Eisenia* in Hainan area

The causative agent of isoyake on Hainan Coast

As the fishermen of Hainan has proposed Shizuoka Prefectural Government to reveal the causative agents of isoyake and to restore the kelp beds. We have struggled for the establishment of restoration techniques and clarification of the phenomenon on the Hainan Coast since 1996.

We divided the causes of isoyake into two factors, trigger and persistence. There is a study of the pioneer work of Kawajiri *et al.*, (1981) about the trigger of isoyake in Shizuoka Prefecture. According to their study, isoyake of the *Ecklonia* forest in southern coast of the Izu Peninsula occurred along with the great meandering of the Kuroshio Current.

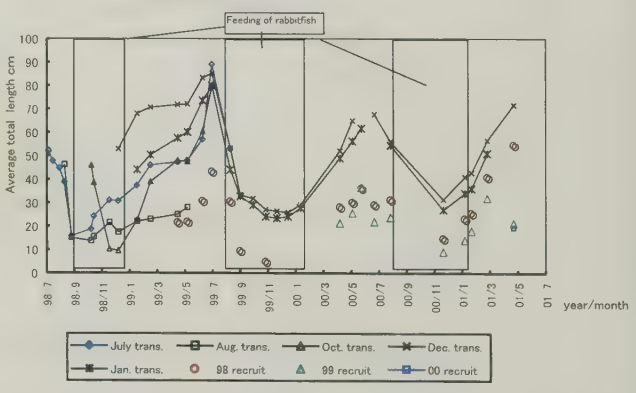

Fig. 3. Changes in total length of *Ecklonia* in transplantation examination

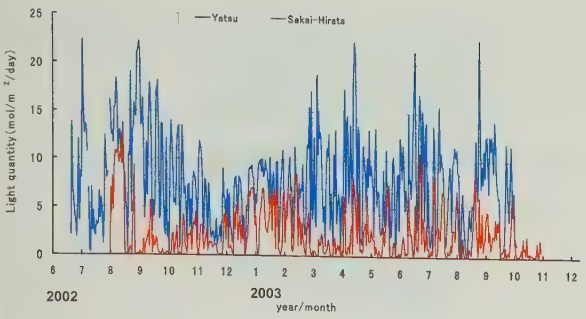

Fig. 4. Comparison of light quantity in *Ecklonia* stands in Izu (yatsu) and Isoyake area in Hainan (Sakai-Hirata)

Fig. 5. *Eisenia arborea* (left) and *Ecklonia cava* (right)

The Kuroshio Current approached Izu Peninsula periodically several times in a century. They pointed out that the coming onshore of the warm current caused the persistence of high water temperature which in turn deteriorated the kelp forests along the coast.

At first, the author examined whether the isoyake on the Hainan Coast was similar to that of the southern coast of the Izu Peninsula, namely the isoyake was caused by high water temperature derived from the approach of Kuroshio Current. However, the isoyake on the Hainan Coast was too complicated than was expected. Before starting, I thought that we should clarify the cause of isoyake before practicing restoration projects. However, because the fishermen's demand for the restoration was enough big, restoration trials were preceded to the clarification of the causative agents. The first trial was the transplantation of *Ecklonia* thalli and the monitoring of their survivals.

Fig. 6. *Ecklonia* on which leaf is lost in the transplant examination

The *Ecklonia* transplantation was done in Sakai Hirata (Fig. 1) in July, August, October, December 1998, and January 1999 (Hasegawa *et al.*, 2003).. Changes in total length of the transplanted thalli and recruits were shown in Fig. 3. The decrease of the total length means disappearance of the blades, while the increase means luxuriant growth of blades.

The observation of the transplanted thalli for three years revealed that environmental conditions were not out of range of *Ecklonia* growth and that recruits appeared on Hainan Coast. In addition, the author found the disappearance of blades of *Ecklonia* thalli from summer to autumn as shown in Fig. 6. There was a bite mark of the arc in the blades left on the thalli.. The mark well agreed with the series of teeth of rabbit fish *Siganus fuscescens* which was known to be herbivorous. Actually, we could observe the scene of browsing on *Ecklonia* thalli by the rabbit fish. These observations strongly suggested that the disappearance of blades from summer to winter was caused by rabbit fish. This is now believed to be one of factors to persist isoyake at Sakai Hirata on Hainan Coast.

In addition, only during one month from October to November in 1999, the blade of *Eisenia* has disappeared at Omaezaki where *Eisenia* stands were left even after the occurrence of isoyake on Hainan coast (Fig. 8). *Eisenia* stands have been observed since 1995 (Hasegawa *et al.*, 2003) and the stands

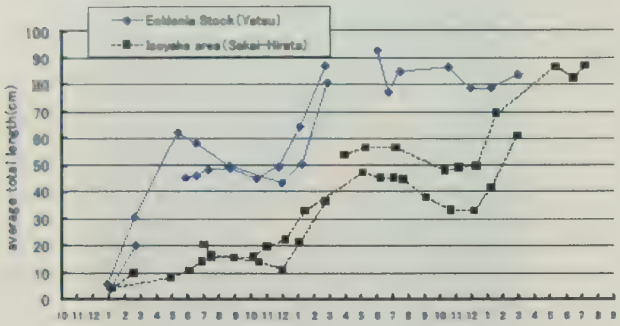

Fig. 7. Comparison of *Ecklonia*' s growth of *Ecklonia* stock in Izu (yatsu) and Isoyake area in Hainan (Sakai-Hirata)

(about 38ha) have remained after the disappearance of kelp forest as large as about 8,000ha.

Nevertheless, in October 1999, the blades of *Eisenia* grown thick disappeared before November 1999 (Fig. 8). There was again loss of blades which left characteristic arc on the survived blades. The detached *Eisenia* blades were found as abundant drifts on the bottom. Mark of the teeth was recognized when the edge of arc on the blade was observed. The characteristic bite marks on *Eisenia* thalli were confirmed to be made by rabbit fish in a feeding experiment in the land-based tank and in observation during diving along the coast.

The survival rate of the *Eisenia* adult was 63% in April 2000. The blades grew thick from spring to summer in 2000. However, the *Eisenia* was browsed again in autumn 2000 by rabbit fish. The density of the *Eisenia* decreased to 1 to 3 individuals/ m^2 in July 2001. Afterwards, survived thalli of *Eisenia* was hardly seen and disappeared at last. As stated above, it was suggested that the feeding by rabbit fish affected greatly to the expansion of isoyake at least during the decline of the population.

In addition, if the diving observation were done on the coast of Hainan, one might notice the low transparency because of high turbidity of the waters. There is a possibility that the turbidity on the coast may also cause isoyake. Relation among the environmental factors (water temperature and light intensity), growth of *Eclonia*, and browsing by rabbit fish was investigated as the next stage. The growth of *Ecklonia* was examined while observing light intensity and water temperature for a long term in the *Ecklonia* populations in Izu peninsula (Yatsu, Fig. 1) and the deforested area (Sakai Hirata, Fig. 1) in Hainan (Shimomura *et al.*, 2005). As a result, a large difference was detected in light intensity between the two sites (Fig. 4) and in the growth of *Ecklonia* (Fig. 7). The relation among the growth of the *Ecklonia,* water temperature and the light intensity was shown in Fig. 9. The growth of *Ecklonia* decreased in higher water temperature, while it increased in lower water temperature. Light related to the growth of *Ecklonia* in lower water temperature. *Ecklonia* thalli grew well when light intensity was high, while they grew little when light intensity is low. The growth of *Ecklonia* was thought to be always inferior because the light environment was bad on the coast of Hainan. If browsing by rabbit fish exceeds the production of *Ecklonia* under such a situation, isoyake can be easily occurred.

The isoyake on the coast of Hainan can be recognized from the result of the above-mentioned research as follows. A light environment deteriorates

Fig. 8. Situation of *Eisenia* Stock around Omaezaki November 5, 1999

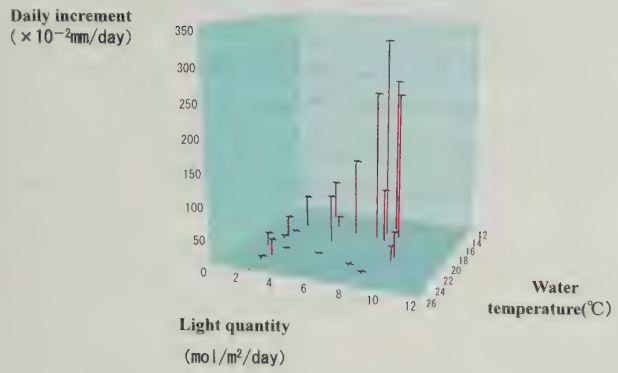

Fig. 9. Relation among the growth of the *Ecklonia* (one year old), water temperature and the light intensity on Hainan Coast.

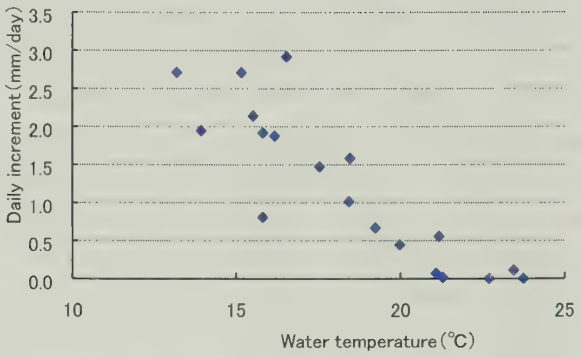

Fig. 10. The relation between the growth of *Ecklonia* (one year old) and water temperature on the coast of Hainan.

as a background of isoyake. As a result, the productivity in *Ecklonia* population was lowered, which in turn caused browsing by rabbit fish to damage the kelp bed.

Is the cause of isoyake in the Izu peninsula a fish?

The Kuroshio Current flowed in the passage of the great meandering after an interval of 13 years in August 2004. Water temperatures were higher than the averaged values from autumn to winter. The water temperature has decreased after a delay of 15 to 20 days compared with the usual year. And, isoyake in the southern coast of the Izu Peninsula was generated as was in the past finding (Kawajiri *et al.*, 1981). As a result of the observation on the generation process of isoyake, it was thought that the browsing by parrotfish might cause the outbreak of isoyake (Hasegawa *et al.*, 2005).

The feeding behavior of the parrotfish to the *Ecklonia* was observed in the field and the die of the parrotfish could cause in the *Ecklonia.*

As for the growth of *Eclonia,* it related greatly to water temperature, and the growth of a central

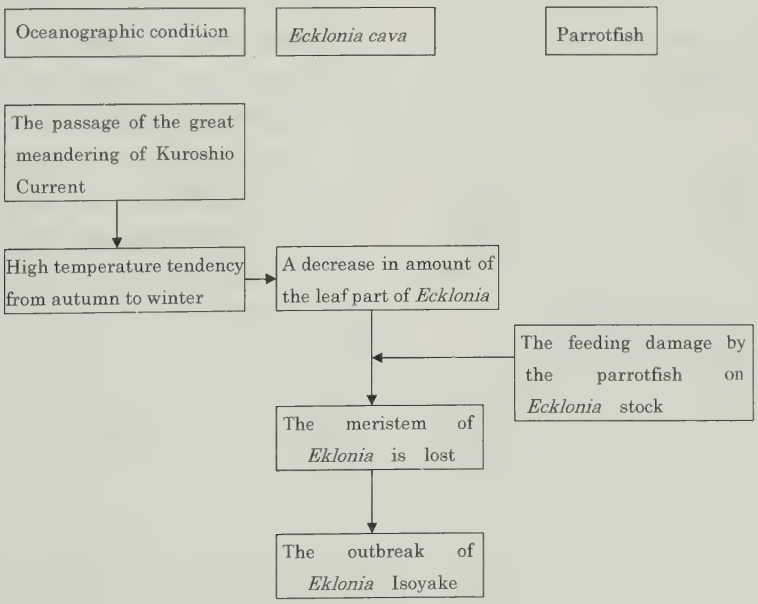
Oceanographic condition
Ecklonia cava
Parrotfish
The passage of the great meandering of Kuroshio Current
High temperature tendency from autumn to winter
A decrease in amount of the leaf part of Ecklonia
The feeding damage by the parrotfish on Ecklonia stock
The meristem of Eklonia is lost
The outbreak of Eklonia Isoyake

Fig. 11. Cause of isoyake along the coast of the Izu Peninsula.

blade in low water temperature was large (Fig. 10). In addition, the *Ecklonia* releases the swimming zoospores in autumn and the blades fall partially. Therefore, it is known the amount of the *Ecklonia* is minimized in December and January (Iwahashi 1968). Because the amount of growth of a central blade was large at a low water temperature, it is thought that the recovery of the blade is closely related to the water temperature.

The blade grew thick when the water temperature decreased ealier. If water temperatures were higher than the average values of the usual years from autumn to winter as 2004, it will be delayed to grow thick in the blade and the stock of the *Ecklonia* decreases.

At this time, if the browsing by parrotfish is synchronized, even the meristem of the *Ecklonia* is lost. If the water temperature decreases earlier, even if there is the feeding damage of the parrotfish, the damage and the blades growing thickly do the balance. As a result, data showed us that the meristem was not lost.

From the above-mentioned, the outbreak mechanisms of the isoyake drive the passage of the great meandering of Kuroshio Current in 2004 (Fig. 11).

Originally, the herbivorous fish like the rabbit fish and the parrotfish have lived in the rocky reef on the Pacific Coast from central to southwest of Japan. Why herbivorous fishes have come to relate greatly to the isoyake? Because the investigation by divers came popular, is herbivorous fishes' feeding behavior clarified? Or, because the sea might become turbid, did the balance of the *Ecklonia* production and the feeding damage collapse? If the seawater temperature rises by global warming, it is possible for herbivorous fishes to reproduce, and to have increased the population. In the future, the study on the herbivorous fishes is necessary to think about the rocky reef ecosystem on the sea in the Kuroshio Current. The feeding damage control of the herbivorous fishes is an important problem to develope restoration of kelp beds in the isoyake area.

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Bull. Fish. Res. Agen. No. 32, 115-118, 2010

Seedling production in *Eisenia arborea* using Suruga Bay deep-sea water for restoration of kelp beds in isoyake area

Kazumi NIMURA [*1], Hiroyuki NODA [*2] and Kazutoshi OKAMOTO [*3]

Abstract; *Eisenia arborea* is distributed from central to southern Pacific coast of Japan. The wild sporophytes of the kelp extincted along the coasts of Omaezaki and Makinohara Cities in Shizuoka Prefecture after deforestation called isoyake (cf. non-urchin barren here) in 1980' s. Fortunately, we have cultured the native sporophytes collected from Omaezaki Cape in our laboratory. Suruga Bay deep-sea water (DSW) is nutrient rich, cold and clean sea water pumped from two depths of 397 and 687m with pipelines. As nitrate and phosphate concentrations of DSW (ex. NO_3=21.1～30.7 μM, PO_4=1.7～2.8 μM in 2007) are higher than that of surface sea water (ex. NO_3=4.0～14.4 μM, PO_4=0.3～1.2 μM in 2007), growth rate of juvenile *Eisenia* sporophyte was higher in DSW than surface seawater. Therefore, we used DSW as culture medium for seedling production. Seedling production was started by the homogenization of the cultured gametophytes with the mixer. Culturing 1～2 weeks later, numerous number of the microscopic free living sporophytes were obtained. These sporophytes was settled on the strings within a day in batch culture and then cultured for about one month in DSW. This seedling of the *E. arborea* was transplanted to isoyake area for restoration of the kelp forests. The method of culture and transplantation on blocks were described here.
Key words: Deep-sea water, *Eisenia arborea*, Isoyake, Seedling, transplantation

Necessity of seedling production in *Eisenia arborea*

Eisenia arborea (Laminariales) is distributed from central to southern Pacific coast of Japan (Yoshida, 1998). The standard Japanese name of *E. arborea* is "Sagarame", which was named after "Sagara Town" (now incorporated in Makinohara City: Fig. 1) near the Omaezaki Cape in Shizuoka Prefecture. *E. arborea* has been utilized as a food in central and west areas in Shizuoka Prefecture; this kelp contains much mucus polysaccharide. Before mid 1980' s, there had been a vast kelp forest of *E. arborea* and *Ecklonia cava* along the coast of Makinohara and Omaezaki Cities (Hasegawa *et al.*, 2003). Then, the kelp forests have decreased and replaced by barren ground (cf. non-urchin barren here). The phenomenon was a type of "Isoyake". There remained a few small kelp forests after mid 1990' s, but in 2000' s, no wild *Eisenia* sporophytes can be found on the coast. Therefore there is no

Fig. 1. Map indicates the location described in the text.

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hope of recruitments in natural condition. However, fortunately, we have cultured the native *Eisenia* sporophytes collected from Omaezaki cape in our laboratory. Our purposes were the production of seedling in the laboratory and transplantation using this seedling for the restoration of the kelp beds. In this paper, the method of preparation of seedling using deep seawater and transplantation on to the blocks are described.

Characteristics of Suruga Bay deep-sea water and juvenile growth

Suruga Bay deep-sea water (DSW) was pumped from Suruga Bay, Yaizu City, Shizuoka Prefecture, from depths of 397 m and 687 m using pipelines (Fig. 1). In this manuscript, the definition of "DSW" is the seawater existed under 200m in depth in the ocean (Nakashima 2002). The deep layer below 200 m in depth is mostly under compensation depth; degradation rate is higher than production rate by photosynthesis (Nakashima 2002). The characteristics of DSW are, 1) rich nutrients: nitrate, phosphate and silicate concentrations of DSW is higher than that of surface sea water (SSW), 2) cleanness: dissolved organic matter, sustained substances, almost no specific pathogens and artificial contaminants are included, 3) Coldness: water temperature of DSW is low below 10℃ and stable.

The fluctuations of nitrate concentration in DSW and SSW in 2007 were shown in Fig. 2. Nitrate concentration of DSW (21.1 ~ 30.7 μM) was higher than that of SSW (4.0 ~ 14.4 μM). Another nutrient, phosphate concentration of DSW was also higher concentration during the year (DSW: 1.7 ~ 2.8 μM; SSW: 0.3 ~ 1.2 μM). We investigated the effects of DSW and SSW as culture mediaum on the growth of juvenile *Eisenia* sporophytes. Juvenile sporophyte was larger in the length in dsw than in SSW at the end of culture (Fig. 3). Therefore we produced the seedling of *E. arborea* using DSW and transplanted to Isoyake area.

Seedling production using Deep seawater

Life cycle of *Eisenia* consists of macroscopic sporophyte and microscopic gametophyte (Hori, 1993), and both life stages are able to culture in our laboratory. Mother sporophytes was culturing in polycarbonate vessel (1kl volume) with DSW and aeration. Usually these sporophytes mature

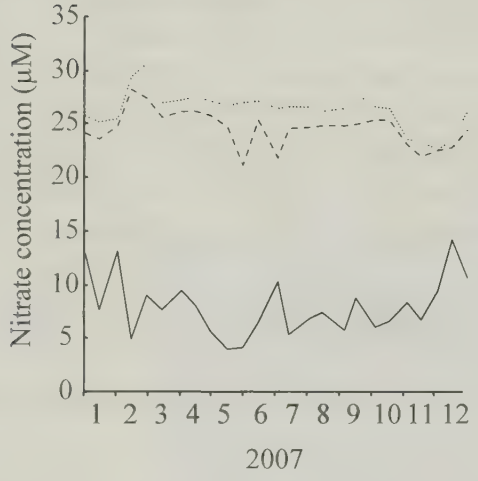

Fig. 2. Fluctuation of nitrate concentration in Suruga Bay deep-sea water (397m: broken line; 687m: dotted line) and surface sea water (solid line) in 2007.

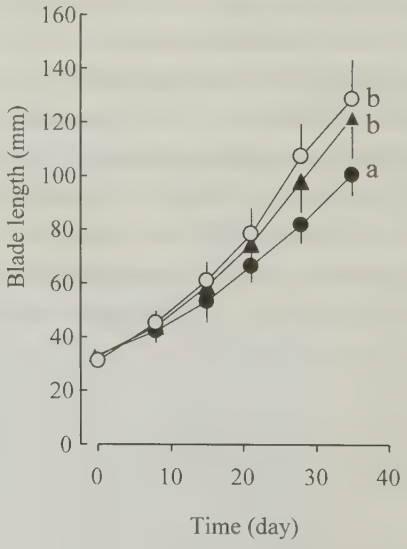

Fig. 3. Changes of the blade length of juvenile *E. arborea* sporophyte cultured in Suruga Bay deep-sea water (397m: ▲; 687m: ○) and surface sea water (●).

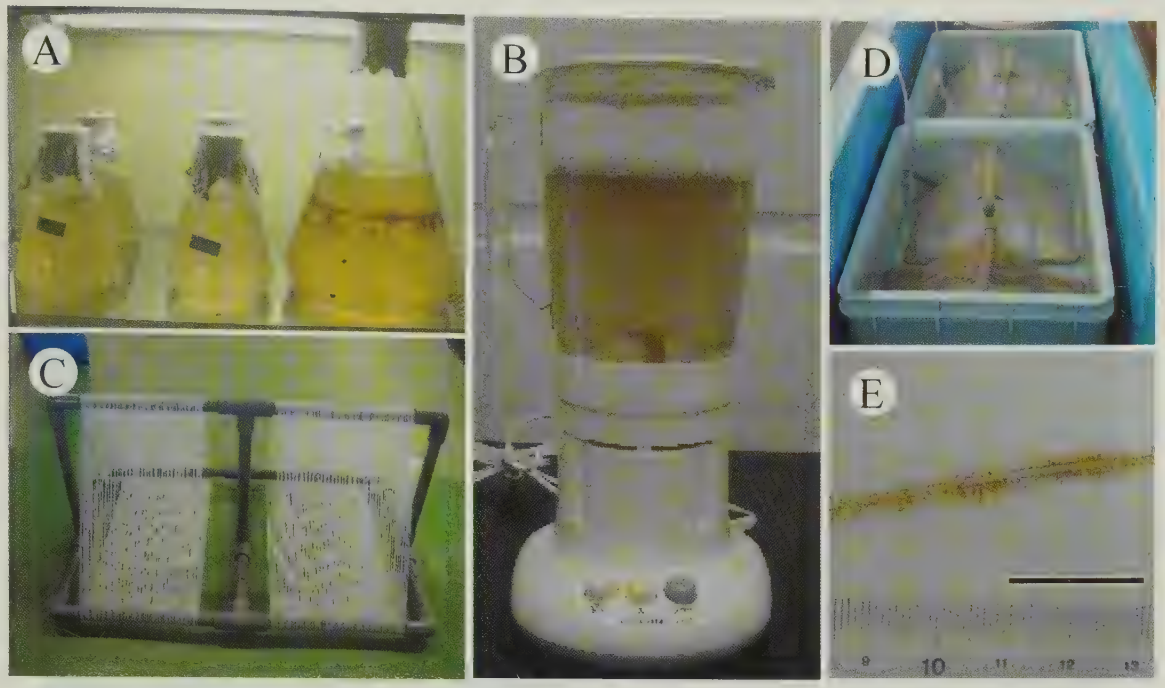

Fig. 4. Photographs of seedling production. A: Propagation of the gametophytes, B: Homogenate of gametophytes, C: Strings wound on the triangular frame, D: Cultivation of seed strings, E: Microscopic sporophytes on seed string (scale bar indicates 2cm).

in autumn, and we obtained zoospores from sori formed on the blades. The zoospores were cultured under 40 ~ 60 μmol m^{-2} s^{-1} (light: dark cycle=12hr: 12hr) at 18℃ in filtered and autoclaved seawater. After the zoospores differentiated to male and female gametophytes. The gametophyte were cultured under 20 ~ 80 μmol m^{-2} s^{-1}(light: dark cycle=12hr: 12hr) at 18℃ with gently stirring or batch culture in modified Provasoli' s enriched seawater (PESI) without iron (Fig. 4 A). Maturation of the gametophyte is needed iron above 2.0 mg l^{-1} in *Saccharina* (*Laminaria*) *angustata* (Motomura *et al.*, 1981), and we observed same phenomenon in *E. arborea* (Nimura *et al.*, 2005). We could stock the gametophytes for several years in this condition.

Seedling production was started by the homogenization of the cultured gametophytes. The gametophytes were homogenized with the mixer to cut into pieces of the filamentous gametophytes (Fig. 4 B). These gametophytes were cultured in PESI with gently stirrer or aeration under 40 ~ 60 μmol m^{-2} s^{-1} (light: dark cycle=12hr: 12hr) at 18℃. After 1 ~ 2 weeks later, we could obtain numerous numbers of the microscopic free living sporophytes. These sporophytes were scattered on the strings (approximately 1 mm in diameter) wound on the triangular frame made from vinyl chloride pipe (Fig. 4 C) in the same vessel filled with DSW. DSW was filtered with cartridge filter (pore size: 0.45 μm) to prevent propagation of contaminated algae and organisms because DSW contains a little number of the microphytes. After the sporophytes were settled on the strings, they were cultured in filtered DSW at approximately 80 μmol m^{-2} s^{-1}(light: dark cycle=12hr: 12hr) at 12 ~ 17℃ for about 1 month (Fig. 4 D). As a result, we obtained a large number of the macroscopic sporophytes on the strings (Fig. 4 E). Seeds on strings were cultured for acclimation in the sea under natural condition (Fig. 5 A). One or two weeks later, seed strings were wound to a rope and attached to the concrete reef (Fig. 5 B, C). The concrete reef was set into Isoyake area (Fig. 5 D).

We produced the *Eisenia* seedlings using DSW, and other species, for example, *E. bicyclis*, *Ecklonia cava*, *Saccharina* (*Laminaria*) *japonica*, *Undaria pinnatifida*. These seedlings can be also used for the cultivation.

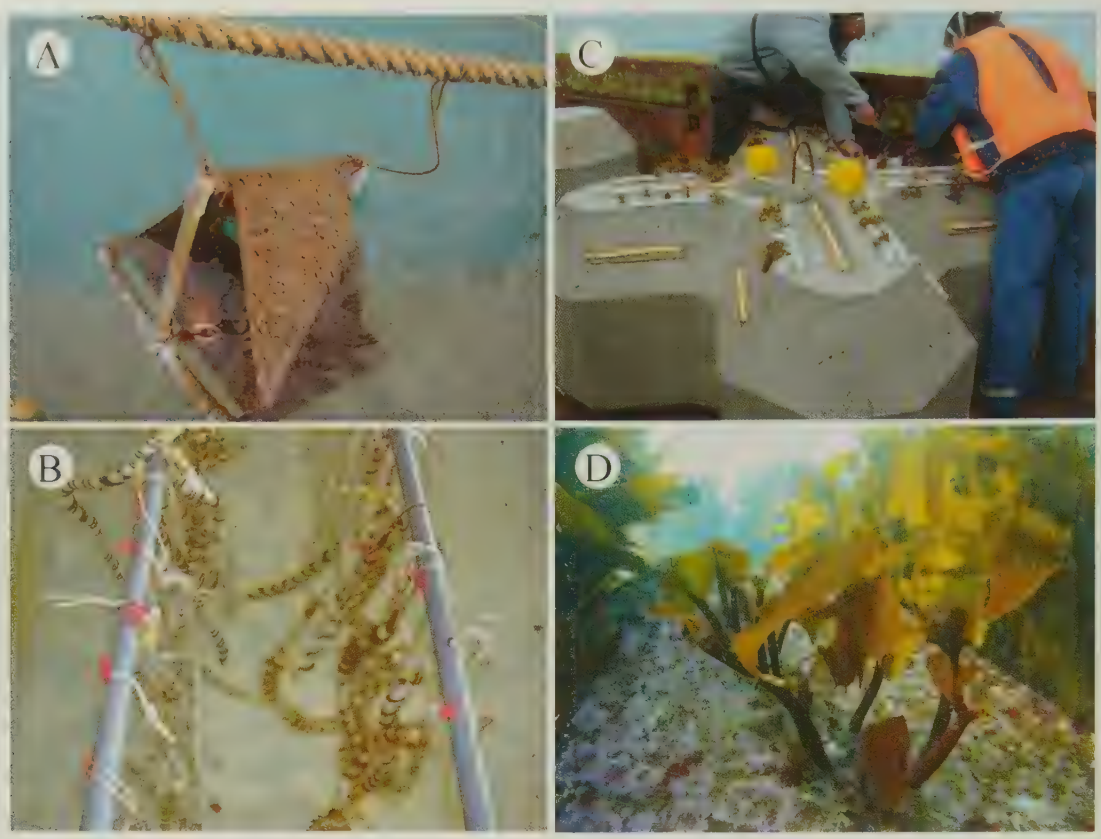

Fig. 5 Photographs of transplanting, A: Cultivation of seed strings in the sea under natural condition, B: Rope wound with seed strings, C: Concrete reef attached with the rope, D: *E. arborea* sporophytes derived from the seed strings on the concrete reef.

Acknowledgment

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Restoration of *Ecklonia cava* forest on Hainan coast, Shizuoka Prefecture

Yukio UNNO [*1] and Masatoshi HASEGAWA [*2]

Abstract: Along the coast of Hainan, extending from Sagara to Omaezaki on the west coast of Suruga Bay, Shizuoka Prefecture, the largest kelp forests comprising of *Eisenia arborea* Areschong and *Ecklonia cava* Kjellman have reduced since around 1985 and almost disappeared by 2000. As the result, catches of abalone and other marine fish and shellfish declined sharply along the coast. In order to avoid extinction of the kelp forest, Shizuoka Prefecture implemented a 'Fisheries Infrastructure Development Project' by deploying blocks implanted with *E. cava* thalli on the barren bottom formerly inhabited by the kelps. Furthermore, we also implemented another project to establish new methods of transplantation to cope with browsing by herbivorous fishes. In the project, restoration of *E. cava* forest was tried using ropes implanted with *E. cava* juveniles and removal of herbivorous fish by fixed net and gill net. The shoreline survey conducted in February 2008 revealed that 55 ha of *E. cava* forest was restored along the coast.

Key words: *Ecklonia cava,* kelp forest, herbivorous fish, browsing, transplantation, gill net, fixed net

Introduction

The kelp forests comprising of *Eisenia arborea* Areschong and *Ecklonia cava* Kjellman along the Hainan coast extending from Sagara to Omaezaki on the west coast of Suruga Bay, Shizuoka Prefecture, was one of the largest stipate kelp forest in Japan.

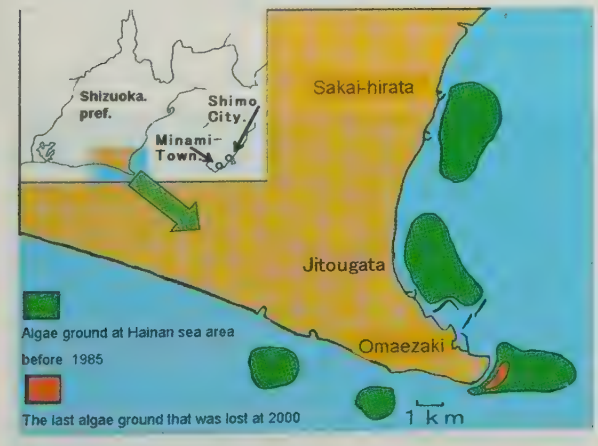

Fig. 1. Reduction of marine forest area

However, the kelp forest has reduced since around 1985 and almost disappeared by 2000. As the result, catches of abalone and other marine fish and shellfish declined sharply along the coast (Hasegawa 2005).

Shizuoka Prefecture, mainly Izu Branch of Research Institute of Fishery carried out investigations to identify the causative agents of the reduction of the kelps and to restore the kelp forest. The restoration trials started in 1996 as a course of Kelp Forest Reconstruction Environmental Research Project.

We implanted *E. cava* on two concrete blocks and transported to a shallow bottom (6m in depth) along the Hainan coast in 1998 (Hasegawa. *et al.*, 2003). As an examination, we deployed a concrete block in the kelp forest of *E. cava* of Shirahama, Shimoda City for 5 months (From November, 1999 to March, 2000) and the block covered with wild *E. cava* juveniles (originated from wild population) was transported to the barren bottom along the Hainan Coast by ship.

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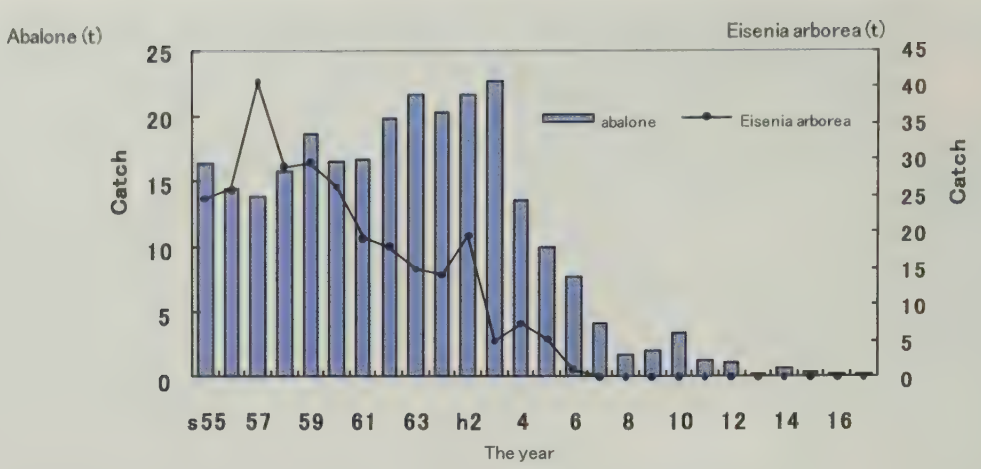

Fig. 2. Catch of abalone *Haliotis* spp. and harvest of *E. arborea* Areschong

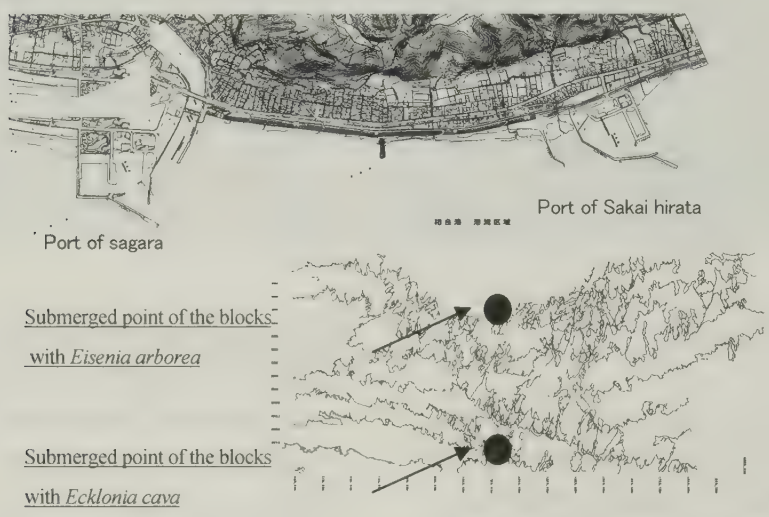
Port of Sakai hirata
Port of sagara
Submerged point of the blocks with Eisenia arborea
Submerged point of the blocks with Ecklonia cava

Fig. 3. Points where the blocks with *Eisenia arborea* and *Ecklonia cava* were deployed.

After deployment, we protected *E. cava* from browsing by herbivorous fishes by surrounding the block with a gill net. We succeeded in the persistence of the *E. cava* stock on the block more than a year (Hasegawa 2005).

Then, we started a large-scale transplantation project of *E. cava* from 2002. In addition, we examined a new method of transplantation and investigated the extent of browsing by herbivorous fish from 2004.

Fig. 4. Browsing by brassy chub *Kyphosus* at Hainan

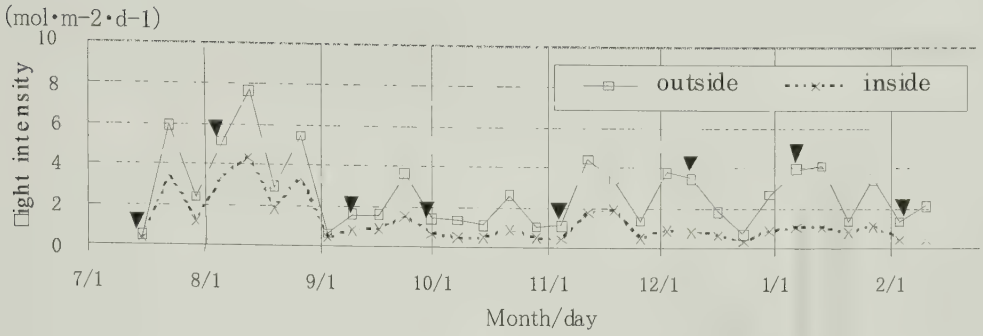

Fig. 5 The change of light intensity inside and outside of the wire cage deployed on Hainan Coast from July 15, 2007 to from Feb. 15, 2008. ▼ : cleaning day

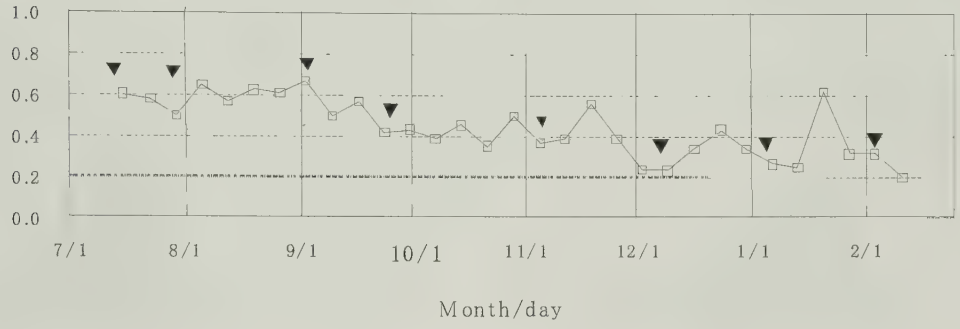

Fig. 6 The change of light intensity by means of inside/outside ratio of the wire cage deployed on Hainan Coast from July 15, 2007 to Feb. 15, 2008.
▼ : cleaning day

The summary of Fisheries Infrastructure Development Project and the examination of the new transplantation method

The summary of Fisheries Infrastructure Development Project.

In 2002 to 2003, we deployed concrete blocks off Minami-izu Town to obtain juveniles from wild *E. cava* forests, and transported these blocks to Hainan. In summer of 2004, just after the transportation of the blocks, the Kuroshio meander occurred and the *E. cava* on the concrete blocks was deteriorated because of high water temperature. Therefore, we suspended the project in 2005, and examined new transplantation method of *E. cava* and *E. arborea.*

The examination of the new transplant method of *E. cava* and *E. arborea* sampling

In addition, we could not transplant *E. arborea* at Minami-Izu because its distribution is restricted to Hainan. On this account, we started examination to implant *E. cava* and *E. arborea* juveniles on concrete blocks manually and deployed them to the bottom of Hainan at 2005.

We implanted juveniles of *E. cava* and *E. arborea* onto 19 concrete blocks using adhesive and deployed them at a depth of 6m. We also implanted *E. cava* on 21concrete blocks and deployed at a depth of 10m.

As the result of monitoring, we confirmed the growth of the transplanted *E. cava* and *E. arborea* juveniles as well as the appearance of *E. cava* recruits in 2006. Therefore, we adopted the transplantation method for further studies. However, no successful transplantation has been achieved in *E. arborea* yet.

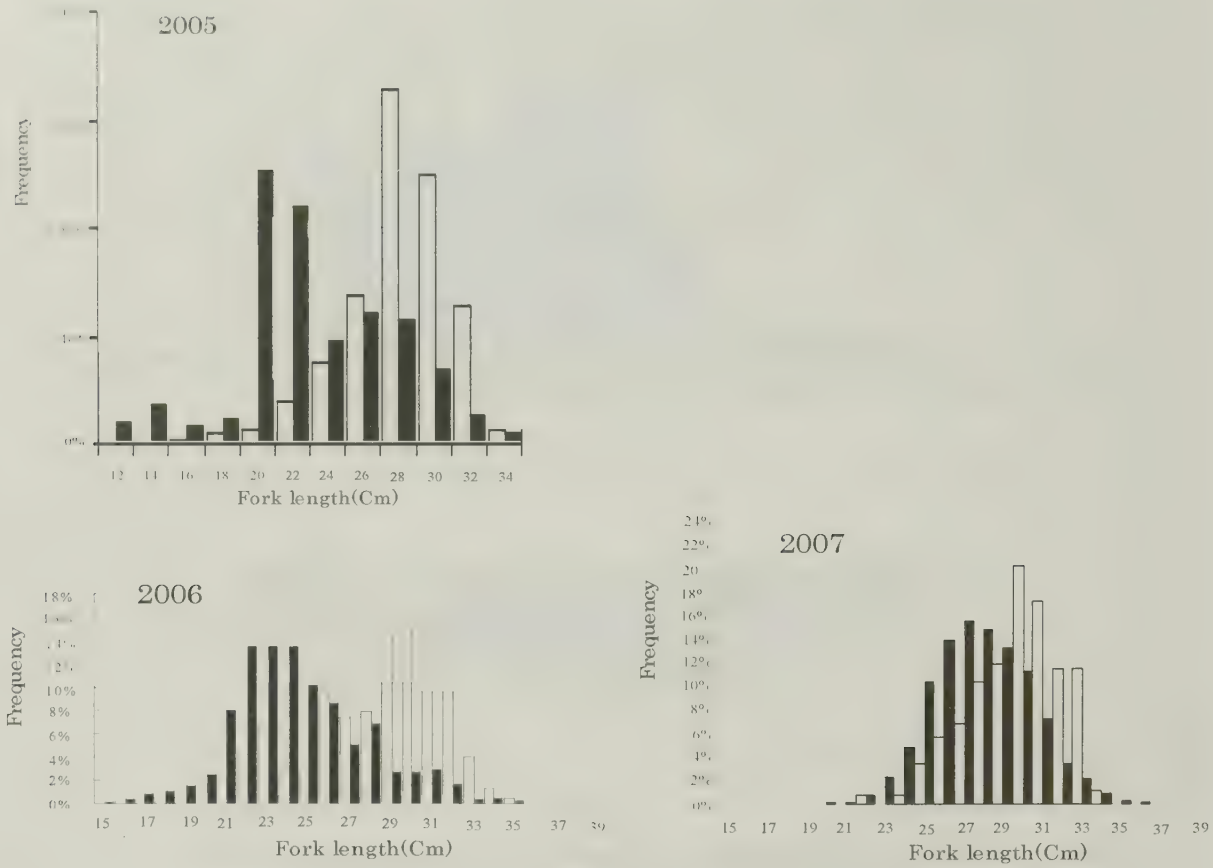

Fig. 7 Frequency distribution for the fork lengths of the rabbit fish. (2005－2007)
□ : Gill net ■ : Fixd net

The browsing on marine algae by herbivorous fishes

The stomach contents of fish caught by the gill net

On Hainan Coast, we investigated the stomach contents of fishes, caught by gill net. We caught 3796 fishes of 95 species in the 132 trials of gill net from June to December 2005. In the investigation, among the fishes, a rabbit fish *Siganus fusucescens,* a parrot fish *Calotomus japonicus* and a surgeon fish *Prionulus scalpus* contained abundant fragments of marine algae in the stomachs. The rabbit fish and surgeon fish was found to eat brown and red algal fragments, while the stomach contents of a parrot fish was occupied by green, brown and red algae.

The feeding behavior of fish monitored with underwater VTR

We filmed the feeding behavior of the fish browsing on *E. cava* with underwater VTR on Hainan Coast for 24 hours. We confirmed that one rabbit fish *Siganus fuscescens* and six brassy chubs *Kyphosus gibbus* browsed *E. cava* in August and September, respectively.

All of these data showed that the causative browsers on Hainan Coast were parrot fish, rabbit fish, surgeon fish, and brassy chub.

Protection of seaweeds from browsing

We carried out two measures to protect *E. cava,* caging with wire and removal of the herbivorous fish by gill nets.

Wire cage and its problems

We built a cage with wire on the concrete pedestal and installed the block on which *E. cava* were transplanted with adhesive. The caged block was deployed at a depth of 8 m on Hainan Coast.

Using the caged block, *E. cava* survived, but could not grow because of poor light condition (Fig. 5, 6).

Fig. 5 shows the changes of light intensity inside (dotted) and outside (solid) of the cage from July 15, 2007 to February 15, 2008. The light intensity was lower inside than outside of the cage. Fig. 6 shows the changes of light intensity by means of inside/outside ratio of the wire cage. The ratio decreased from around 60% to 20-30% after 6 months though the cage was cleaned periodically.

Removal of herbivorous fishes

In order to decrease the amount of browsed thalli, we kept on removing herbivorous fish, by using the gill net and fixed net since 2005 to 2007. In Table 1, the numbers of herbivorous fishes caught by these nets were summarized.

The numbers of herbivorous fishes caught by the fixed net and by the gill net were 8,686 to 4,032 and 627 to 242, respectively. The results show that the fixed net seems to be the better way of removing herbivorous fishes from the vicinity of the target seaweed beds.

Fig. 7 shows the frequency distribution in fork length of the rabbit fish *S. fuscescens* caught by the fixed net and the gill net from 2005 to 2007. The mode of the fork length of fishes caught by the gill net were 30cm in 2007, 31cm in 2006 and 28cm in 2005, while the mode of the fork length of the fishes caught by fixed net was 27cm in 2007, 25cm in 2006, and 20cm in 2005. The minimum of the fork length of the fish caught by fixed net were 21cm in 2007, 15cm in 2006 and 12cm in 2005.

Table 1. The numbers of herbivorous fishes caught by gill net and fixed net

Year	2005	2006	2007
Gill net	283	627	242
Fixed net	5740	8686	4032

Recovery and expansion of the *E. cava* forest in Hainan sea area.

We carried out shoreline survey in order to monitor the effect of the project of *E. cava* transplantation combined with removal of herbivorous fishes by gill net and fixed net in August 2007 and February 2008. The length of the line was 10,000 meters and 196 points were monitored on 20 lines extended rectangular to the shoreline (Fig. 8).

Shoreline survey at August 2007

Fig. 9 shows the result of the survey in August 2007. We confirmed recovery of *E. cava* at 100 of 196 points on the 20 survey lines. Both adult and juvenile of *E. cava* were found at each point, particularly abundant at the central part of the survey area. Using the data, the recovery area of *E. cava* was estimated at about 39 ha.

Shoreline survey in February 2008

Fig. 10 shows the result of the shoreline survey in February 2008. We confirmed the occurrence of *E. cava* at 136 of 196 points on the 20 survey lines.

The ratio of adult *E. cava* containing lateral blade increased comparing with at the result in August 2007. The estimate of the recovery area of *E. cava* was about 55 ha, showing the expansion during the half past year.

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Fig. 8. The range of the shoreline survey.

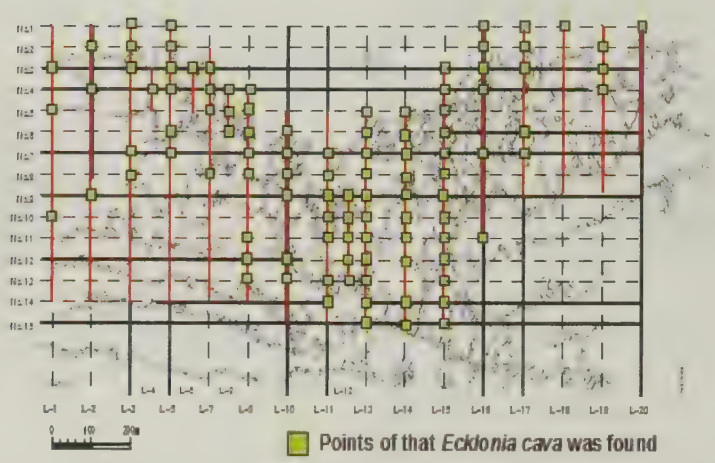


Fig. 9. The distribution of *E. cava* of Hainan coast in August 2007.

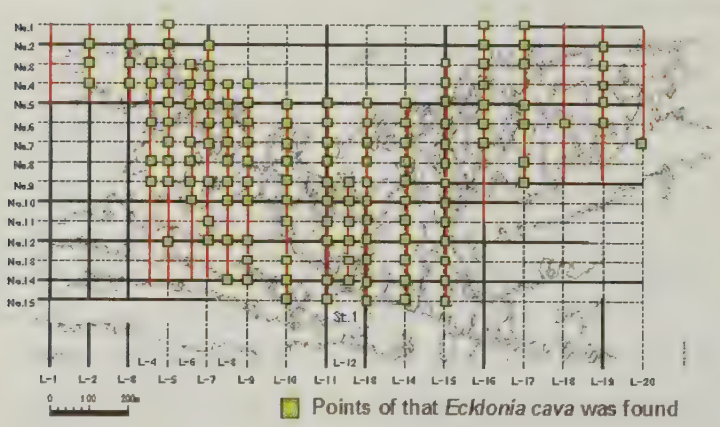
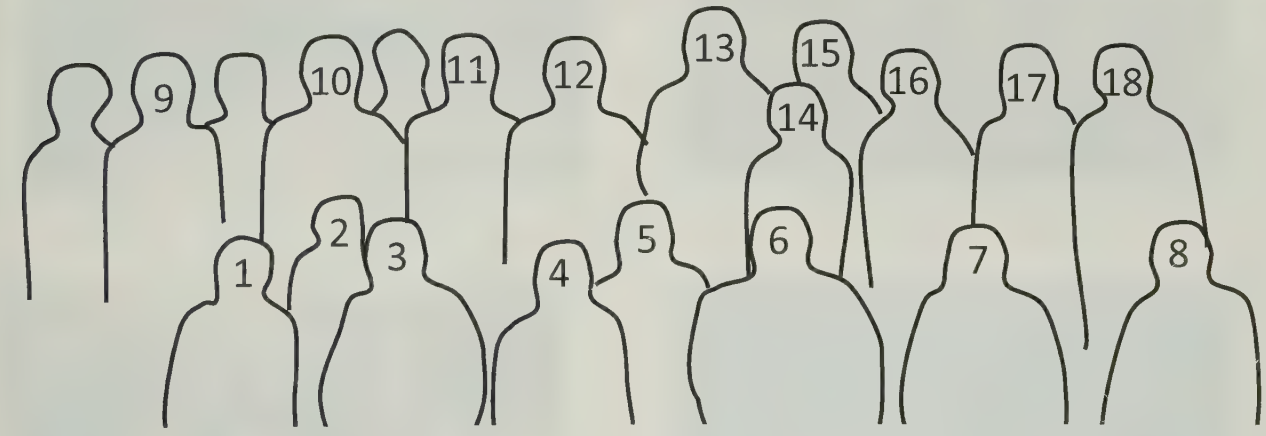


Fig. 10. The distribution of *E. cava* on Hainan Coast in February 2008.

Photograph 2008.8.1

Speakers and representatives in Isoyake Recovery Symposium



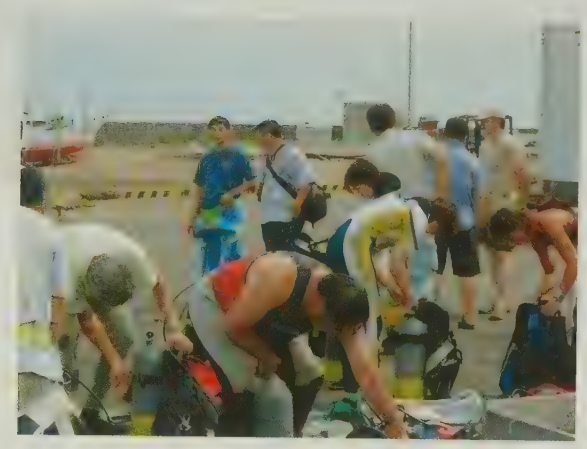
1. Kousuke YATSUYA
2. Shigeru KAWAMATA
3. Tokio WADA
4. Seiya TAINO
5. Daisuke MURAOKA
6. Daisuke FUJITA
7. Michael H. GRAHAM
8. Akito SATO
9. Hisami KUWAHARA
10. Chien-Chang TSENG
11. Jui-Sheng CHANG
12. Osamu HASHIMOTO
13. Put O. Ang, Jr.
14. Atsuko YAMAGUCHI
15. Dmitry GALANIN
16. Delin DUAN
17. Rae-Seon KANG
18. Tsutom MIYATA

Photographs 2008.8.2-8.4

Field Trip in Shizuoka prefecture (Hainan district and Numadu district)

Movement by chartered bus

Lunch



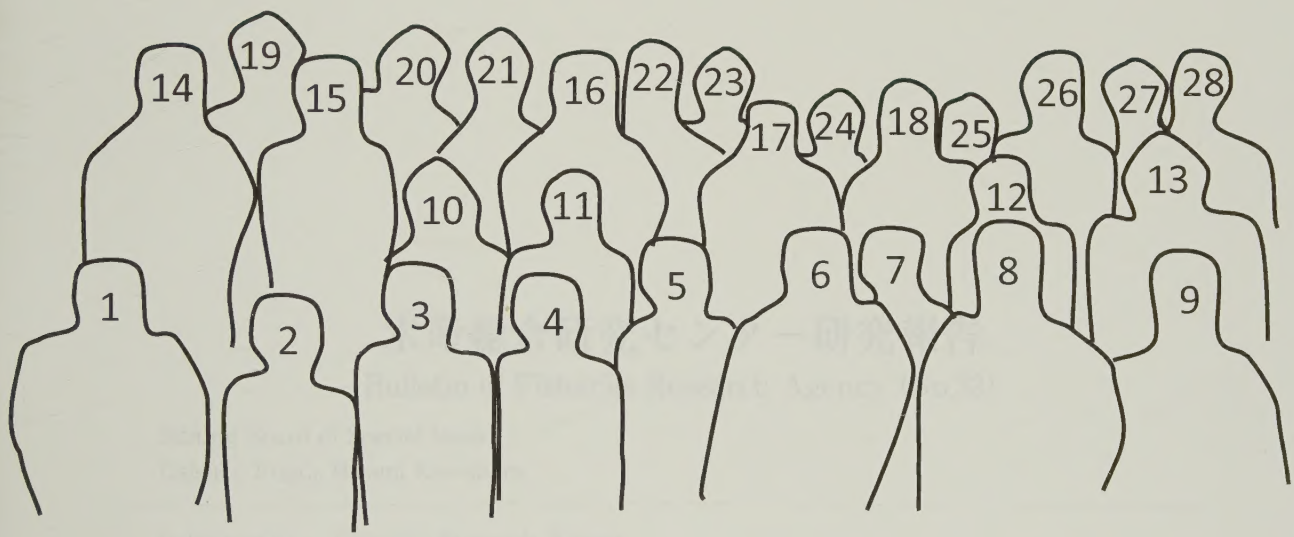
Preparation of observation

Observation from shipboard

Observation by scuba diving

Presentation and discussion on Isoyake recovery in Sizuoka prefecture

Participants of field trip



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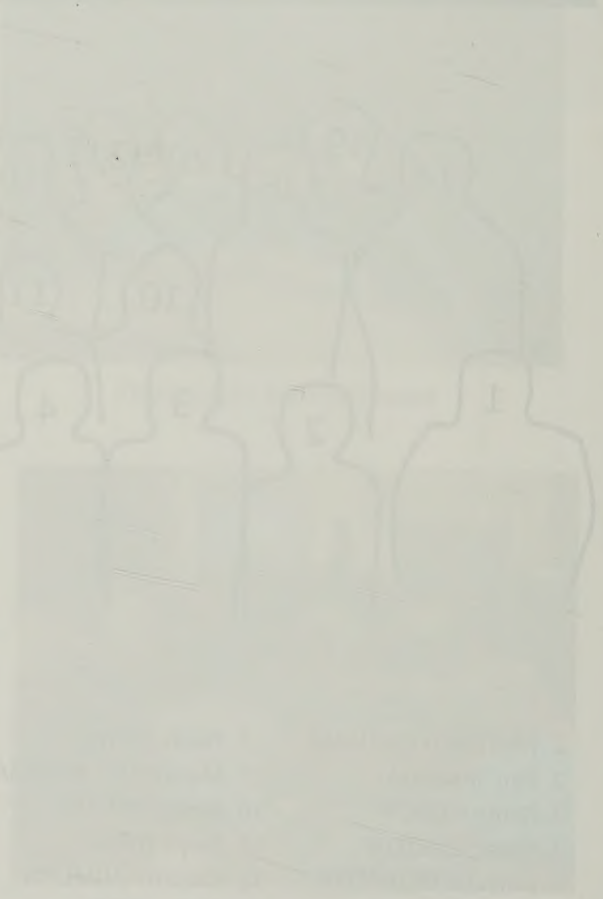

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